DEVELOPING A DECISION SUPPORT SYSTEM FOR EMERGENCY MANAGEMENT SERVICES IN THE FAIRBANKS NORTH STAR BOROUGH, ALASKA

By

Katherine E. Schaefer

RECOMMENDED: ______________________________

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Advisory Committee Chair

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Chair, Department of Geology & Geophysics

APPROVED: ______________________________
Dean, College of Natural Science & Mathematics

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Dean of the Graduate School

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DEVELOPING A DECISION SUPPORT SYSTEM FOR EMERGENCY MANAGEMENT SERVICES IN THE FAIRBANKS NORTH STAR BOROUGH, ALASKA

A

THESIS

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By

Katherine E. Schaefer, B.S.

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Abstract

Every year the Fairbanks North Star Borough (FNSB), in interior Alaska, responds to common emergencies, as well as disasters of varying types. This research first tested several geographic information systems (GIS) based network analysis models to demonstrate how these models could serve as 'decision support' tools for emergency planning and response. Six network analysis models based on FNSB data were evaluated to determine the response times of local fire stations. Each model was tested against real call times and simulated summertime fire emergency response call times to verify model accuracy. The simulated times matched the modeled predictions with remarkably high R^2 values of 0.946, 0.941, and 0.940 for conditions that represented no adjustment to road data, a time penalty for slopes, and a small time penalty for all turns, respectively. The corresponding results with culled real-time call data had a much lower accuracy of 0.403, 0.429, and 0.415, respectively. The lower accuracy for real-time data was primarily due to discrepancies in response time recording protocols. This study also divided FNSB into evacuation zones and created a map book with critical infrastructure and key resources necessary for improved emergency management.

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Chapter 1: Introduction

1.1 Background and Motivation

As the world enters the 21st century dramatic changes are taking place on a local, regional, and global scale. The total world population stands at seven billion people and by 2050 it is estimated to be just under ten billion (Population Reference Bureau, 2012). More than half of this population lives in urban areas (UNDESA Population Division, 2007). This rapid growth in population and increasing congestion poses new challenges, especially for organizations responsible for urban planning and emergency response.

In parallel with population growth, the world is witnessing a rise in the number, magnitude, and frequency of natural hazards. Though, “natural hazards by themselves do not cause disasters – it is the combination of an exposed, vulnerable and ill prepared population or community with a hazard event that results in a disaster” (ISDR, 2008).

Regardless of the cause, once a disaster occurs, it can have huge economic consequences. In the 1990s, just the cost of property damage from natural hazard related disasters world-wide was over $652 billion (IEG, 2012). In the last decade 2.6 billion people were affected by natural disasters compared to 1.6 billion people affected from 1990 through 2000 (IEG, 2012).

Nationally and regionally there are an alarming number of disaster occurrences. In 2011 alone there were 99 Major Disaster Declarations (FEMA, 2012) and the American Red Cross responded to 68,387 disasters, over 300 of those in Alaska (Red Cross, 2012). Undoubtedly, there is a strong need to be prepared for responding to a variety of disasters and emergencies at all levels, particularly at the community level.

This community level need was the driving inspiration for this research work. This research addresses the challenges posed in preparing for and responding to disasters in the Fairbanks North Star Borough (FNSB), situated in interior Alaska. FNSB, or the Borough, used interchangeably throughout this thesis, covers a large area in a high latitude setting. The relatively small population of FNSB is dispersed over a large area and represents a mix of rural and urban populations. FNSB faces a variety of hazards including, but not limited to, severe floods, wildfires, winter storms, and occasional earthquakes.

In the summer of 2011 there were two wildfires in particular that highlighted the need for a more geospatially enabled evacuation plan for emergency response. The first of these wildfires was the Moose Mountain fire that started in May 2011 on the Murphy Dome Ridge just north of Fairbanks. It burned a total of 858 acres, a relatively small area compared to other Alaskan wildfires. However, its proximity to 1,319 houses within a five mile radius, with a possible 3,823 people affected made it particularly significant. This fire heightened the need for a quick and easy-to-use resource that would allow emergency planners and responders to estimate how many people and structures would be affected given various possible routes the fire could take, as well as the location of major transportation routes, critical infrastructure, and key resources. The real life emergency situation during the course of this research provided motivation to further expand the research work to include a detailed geospatial analysis of FNSB, and to generate an improved map book as a practical deliverable product to emergency responders.

1.2 Terms and Definitions

In the field of emergency management, including risk analysis and public policy, terms can be defined differently by various agencies and user groups, sometimes with little consensus. This research largely conforms to the use of these terms as defined by Perry and Lindell (2007) and the FEMA Glossary (2012).

Catastrophe: Large scope of impact event that crosses multiple communities, produces very high levels of damage and social disruption, and sharply and concurrently interrupts community and lifeline services (Perry and Lindell, 2007). A large scale disaster.

Critical Infrastructure: Systems, assets and networks, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety or any combination of those matters (FEMA Glossary, 2012).

Decision Support System: Defined broadly as interactive computer-based systems that help decision-makers use data and models to solve ill-structured, unstructured, or semi-structured problems (Sprague and Watson, 1993).

Disaster: Sudden-onset occasions that seriously disrupt social routines, cause adoption of unplanned actions to adjust to the disruption, are designated in social space and time, and that endanger valued social objects (Perry and Lindell, 2007).

Emergency: Unforeseen but predictable narrow-scope incidents that regularly occur (Perry and Lindell, 2007).

Emergency Plan: The ongoing plan maintained by various jurisdictional levels for responding to a wide variety of potential hazards (FEMA Glossary, 2012).

Essential Functions: The definition varies, but usually these functions are ones that create negative outcomes within 24 hours of curtailment (Perry and Lindell, 2007).

Evacuation: The relocation of threatened populations to places outside the hazard impact area (Perry and Lindell, 2007).

Hazard: Natural or man-made source or cause of harm or difficulty (DHS, 2010).

Key Resources: Any publicly or privately controlled resources essential to the minimal operations of the economy and government (FEMA Glossary, 2012).

Major Disaster Declaration: Under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, any natural catastrophe (including any hurricane, tornado, storm, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm or drought) or, regardless of cause, any fire, flood or explosion in any part of the United States that, in the determination of the President, causes damage of sufficient severity and magnitude to warrant major disaster assistance under the Stafford Act to supplement the efforts and available resources of states, local governments and disaster relief organizations in alleviating the damage, loss, hardship or suffering caused thereby (FEMA Glossary, 2012).

Response: Immediate actions to save lives, protect property and the environment and meet basic human needs. Response also includes the execution of emergency plans and actions to support short-term recovery (FEMA Glossary, 2012).

1.3 Study Area

Location

FNSB lies in interior Alaska and is centered at 65°N latitude (Figure 1). The Borough spans a large area of 7,443 sq. miles and includes two major cities, Fairbanks and North Pole, as well as many smaller communities, with a combined population of nearly 98,000 people (U.S. Census Bureau, 2012). FNSB has three major highways. The Steese Hwy (AK Hwy 6) starts within the Borough and dead ends at a smaller community, Circle, north-east of the FNSB boundary. The Elliot Hwy (AK HWY 2) heads north through the Borough up to Prudhoe Bay. The Elliot Hwy also heads south-east of Fairbanks, turning into the Richardson Hwy, and eventually turning into the Alaska Hwy that continues into the Yukon Territory, Canada. The Parks Hwy (AK HWY 3) is the main corridor for supplies and people in and out of the Borough. While it ends in Fairbanks, it starts 358 miles to the south in Anchorage, the largest city in Alaska and the major port of goods and resources. With only three highways in and out of the Borough, only two of which lead to a city that could provide evacuation relief and resources, disaster planning is particularly challenging.

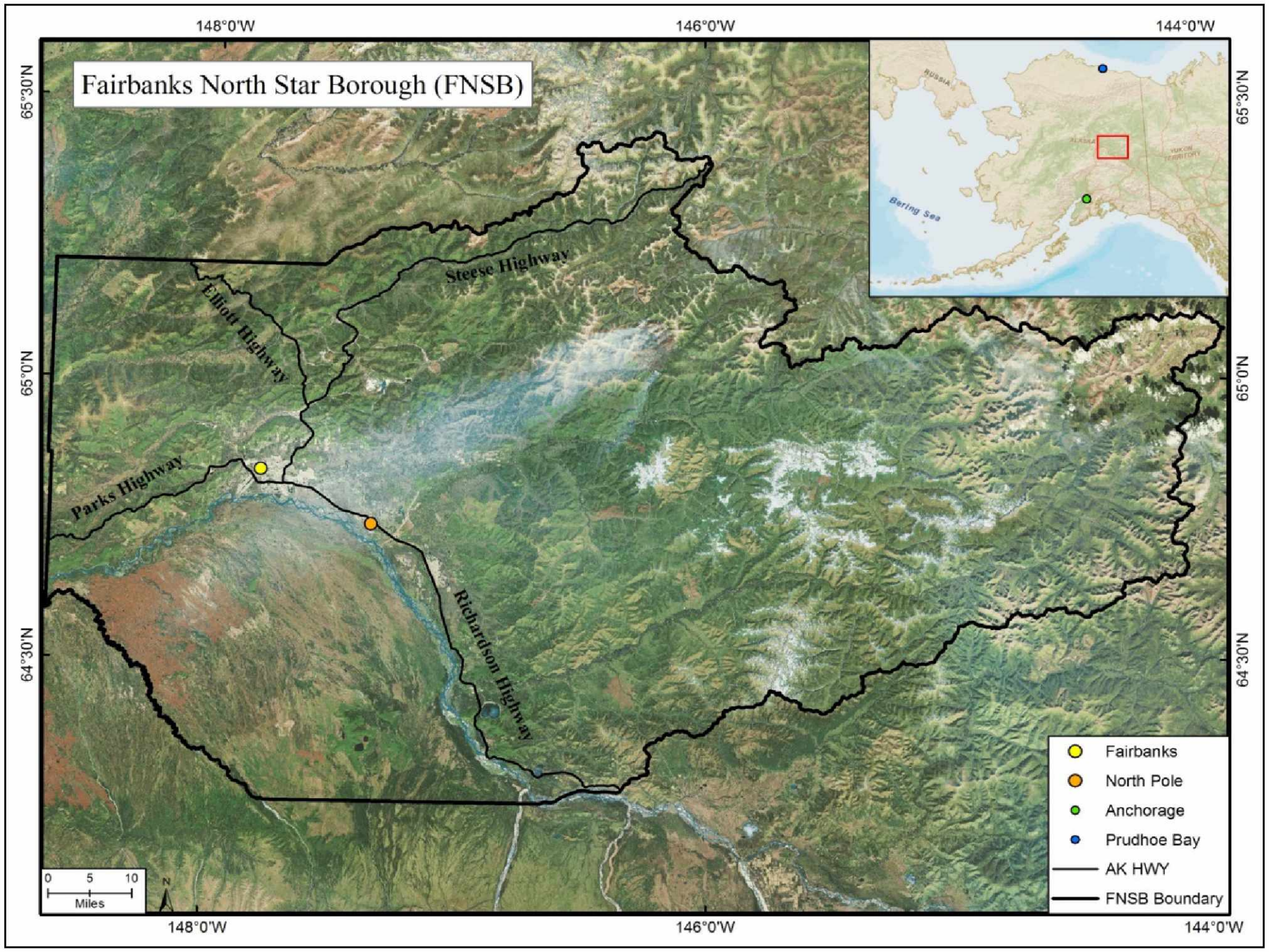

Figure 1: Map of the Fairbanks North Star Borough. The inset map shows the state of Alaska with Russia to the left and Canada to the right. The red outline is the area that is shown in the main map.

Climate

Interior Alaska has a subarctic, continental climate with long, cold winters and warm summers (Stafford et al., 2000; Shulski and Wendler, 2007; Wendler and Shulski, 2009). FNSB has an annual monthly mean temperature range of -19° F to 68° F and a mean annual precipitation of 10.81inches (Alaska Climate Research Center, 2012). According to climatological observations over the past 100 years, FNSB has seen a mean annual temperature increase of 2.52°F, as well an increase in the length of the summer growing season (Wendler and Shulski, 2009). FNSB is dominantly a boreal forest with white and black spruce trees, birch trees, and cottonwood as the main vegetation cover (Wendler et al., 2011; Bieniek et al., 2012).

Wildfires

Due to its ecology and location within the boreal forest, FNSB is very prone to wildfires. The Alaska Fire Service (AFS), a division of the Bureau of Land Management, reported that since 1939 2,982 fires that have burned a total of 2,521,407 acres just within FNSB (AFS, 2012). In the past 10 years FNSB has had 963 fires that burned a total of 891,983 acres (AFS, 2012).

Earthquakes

According to the Alaska Earthquake Information Center (AEIC), Alaska has had three of the ten largest earthquakes ever recorded in the world. The state also has had ten out of fifteen of the largest earthquakes recorded in U.S. history and witnesses approximately 24,000 earthquakes a year (AEIC, 2012). Most of the earthquakes that occur are situated along the Aleutian Islands and around the Anchorage area. These earthquakes can still pose a threat to FNSB if they cut off the shipment of resources and goods from Anchorage to Fairbanks. Since 1904 FNSB itself has been the center of 65 earthquakes over a 4.0 on the Richter scale (AEIC, 2012).

Floods and Winter Storms

Earthquakes and wildfires are not the only threats to FNSB. The Borough also has yearly floods and winter storms that can quickly cut off neighborhoods and potentially leave thousands without power. In the past ten years Alaska has had 16 major disaster declarations (FEMA, 2012). Four of these major declarations were within the Borough: two flooding (2002, 2008), one earthquake (2002), and one winter storm (2011) (FEMA, 2012).

1.4 Problem Definition

While FNSB has a wealth of geospatial data and information, it lacks an efficient and structured geodatabase that is specifically tailored to support decision-making processes during emergency situations. Quality checks of the available data, efficient organization of the data, and developing tools (algorithms, queries) that could meaningfully search through the database to detect relevant information are important steps toward developing an efficient decision support system for emergency response in the Borough.

1.5 Goals and Objectives

The goal of this research is to use geospatial technologies to build a foundational dataset and demonstrate a 'proof of concept' for generating cartographic products and network analysis tools for emergency management, using a subset of data that has been verified and corrected. To achieve this overarching goal the specific objectives are:

1. Design and create a geodatabase that includes local road data, speed limits, address points, census population data, and critical infrastructure.
2. Build a network of roads, elevation data, and resource data to be used for a Borough wide network analysis.

3. Run network analysis models using different scenarios for unadjusted road data, and road data that adds time penalties for high slopes and for turn-times.
4. Test network analysis results with real emergency call-time data and simulated fire response call-time data to determine optimal network for FNSB.
5. Divide the Borough into evacuation zones and create a map book with a page dedicated to each zone that includes critical information needed to evacuate that zone.
6. Combine the map book with the network analysis to create evacuation routing maps.

The research results and published map book will enhance FNSB's Emergency Operations Plan (EOP), as well as provide a go-to resource during times of crisis.

1.6 Thesis Structure

This chapter (Chapter 1) provides the motivation, background, and goals of this research. Details of the data used in this research are given in Chapter 2. Chapter 3 discusses the creation of a geodatabase and the pre-processing of the data. The specifics of the network analysis of the FNSB data are explained and a sample network analysis is presented in Chapter 4 (complete results are presented in Appendix A). Chapter 5 describes the methods used for creating the evacuation zones and the map book, and presents a sample result (the complete evacuation map book is presented in Appendix C). In Chapter 6 the final conclusions and recommendations are presented.

Chapter 2: Data

To create and run a network analysis for FNSB and to produce cartographic products from the analysis results, various types of satellite and GIS data, as well as ancillary data from several local and national sources were used. The type and source of each dataset is described here.

2.1 Remote Sensing Data

There were two reasons for incorporating remote sensing data in the analysis. A Digital Elevation Model (DEM) was needed for slope analysis. A DEM is similar to a digital image, a continuous raster image, where each pixel is an elevation value instead of a brightness value (Lillesand et al., 2008). Satellite images were also required as a base for cartographic products. Remote sensing data were collected from several sources and are described below.

2010 Fairbanks LiDAR Digital Elevation Model

The Fairbanks Light Detection And Ranging (LiDAR) data used in this analysis were collected by Aero-Metric Inc. in May of 2010. LiDAR is an active remote sensing technique that involves transmitting pulses of laser light toward the ground and measuring the time it takes for that pulse to return. These timed pulses are then converted to distance between the sensor and the surface below (Lillesand et al., 2008). The Fairbanks LiDAR data was collected using an Optech ALTM Gemini onboard a Cessna 320 aircraft. The collection altitude was 1400 meters at a ground speed of 150 kts. The pulse rate frequency was 70 kHz, with a mirror scan frequency of 48 Hz, and a scan angle of twelve degrees. The resulting point cloud was converted to a 1.2 meter resolution bare-earth DEM in geodatabase format by Aero-Metric and then provided to the Borough. The stated accuracy of this DEM is 0.15 meter or better with a nominal point spacing of 0.81 meters (FNSB, 2012). As the LiDAR generated DEM covers only 60% of the roads in the Borough, remaining elevation data was extracted from DEMs provided by the United States Geological Survey (USGS). Figure 2.1 shows an example of the LiDAR data provided by the Borough.

Figure 2.1: Sample of downtown Fairbanks LiDAR DEM. The darkest spots typically represent water sources where the laser pulse was absorbed instead of reflected. The white, brightest spots represent surfaces or edges where the laser recorded a very short pulse return. The variation in gray tones represents different elevation values.

United States Geological Survey DEMs

The USGS DEMs used are part of the current National Elevation Dataset (NED) (Figure 2.2). The NED is a seamless raster product providing elevation data for the continuous United States, Alaska, Hawaii, and the island territories. This data is derived from multiple data sets that are all processed by the USGS to a standard resolution, datum, and coordinate system. Data is available nationally at 30 meter, 10 meter, and 3 meter resolutions depending on the area of interest (USGS, 2006). For the Borough, there was 3 meter resolution elevation data for 3% of the roads not covered by the previously mentioned FNSB LiDAR data, 10 meter resolution for another 30% of the roads, and 30 meter resolution for the remaining 7% of the Borough roads. While all datasets were produced by USGS, they were accessed through Alaska Mapped. Alaska Mapped is the distribution channel for the Alaska Statewide Digital Mapping Initiative (SDMI). SDMI provides access to many different types of data from many local and national agencies, as well as private companies (ASDMI, 2012).

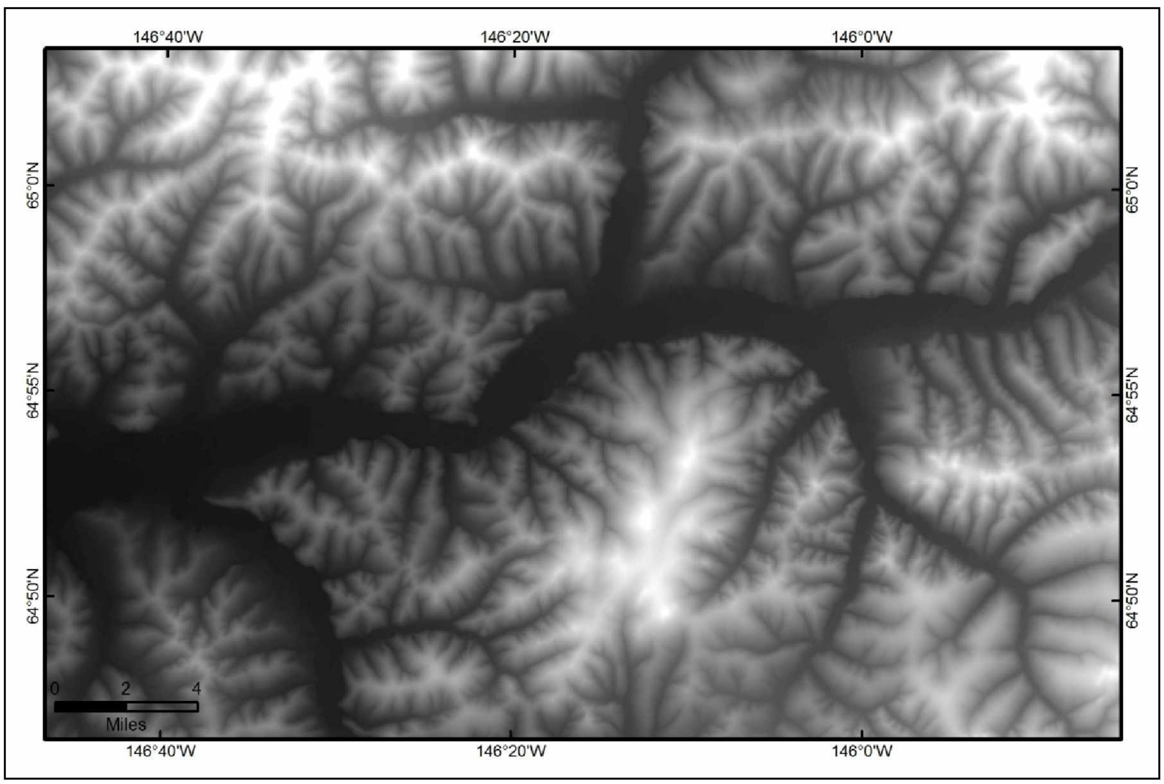

Figure 2.2: Sample of USGS DEM. The brightest spots are the highest elevations and the darkest areas are the valleys and other low lying areas.

Alaska Mapped Best Data Layer (BDL)

The Best Data Layer (BDL) is a Web Mapping Service (WMS) provided by SDMI through Alaska Mapped (ASDMI, 2012). The BDL service provides a continuous imagery base layer for the entire state of Alaska. The BDL has three layers consisting of low, medium, and high spatial resolution. Only the medium and high resolution layers were used in this analysis.

Medium Resolution Layer: The medium resolution layer is a true color Landsat mosaic provided by Earthstar Geographies LLC using imagery acquired from 1988 to 1992 (Figure 2.3). The Landsat program is a collection of Earth-observing satellites jointly managed by NASA and USGS. This particular layer was produced using images from Landsat 5 Thematic Mapper data. The Thematic Mapper is a sensor that collects seven bands in a spectral range of 0.45 - 12.5 µm and a 30 m spatial resolution (NASA, 2012). This medium resolution layer is viewable at scales greater than 15 m per pixel and was used as an imagery base for Borough-wide maps (ASDMI, 2012).

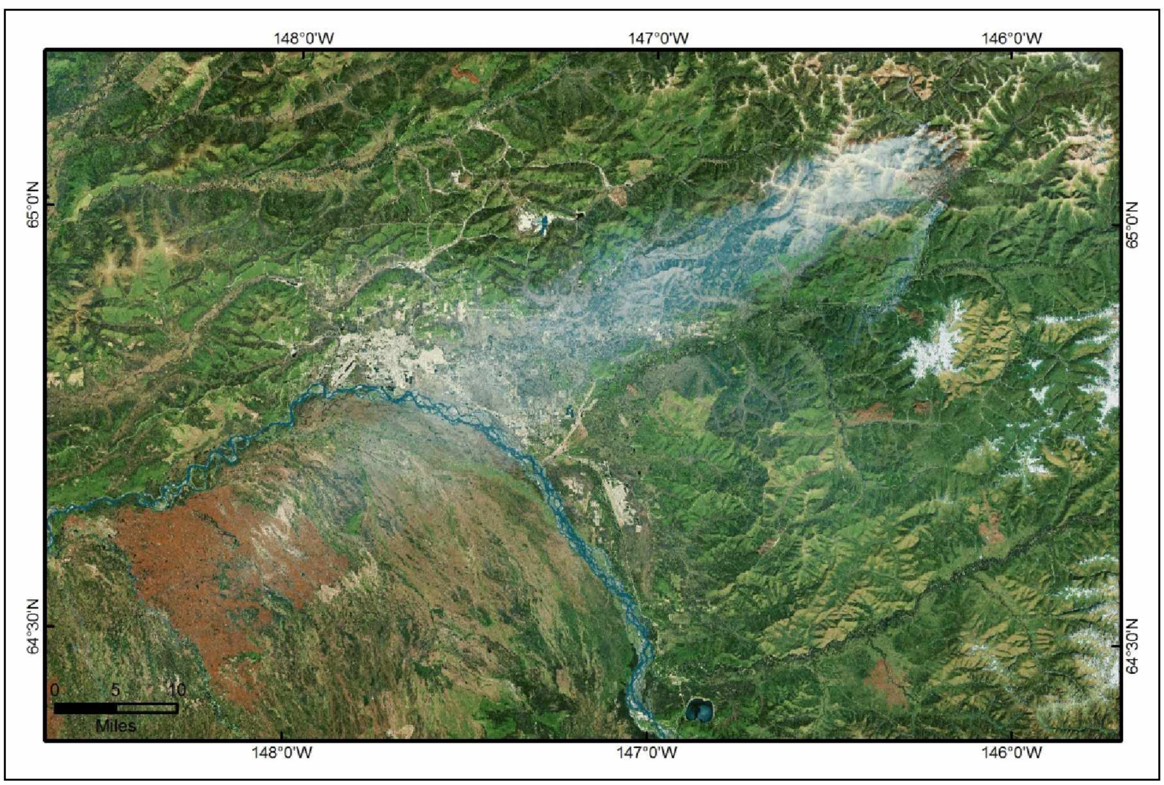

Figure 2.3: Medium resolution Landsat image of FNSB. This was used for Borough-wide maps.

High Resolution Layer: The high resolution BDL layer is comprised of a variety of images and is viewable from 1 m to 25 m per pixel resolution (Figure 2.4). This layer was used as a base image for the color version of the map book and other cartographic products that required high resolution satellite imagery as a base. The sources of this image layer include: Digital Globe, U.S. Department of Agriculture Natural Resources Conservation Service, U.S. Department of Agriculture Forestry Service, U.S.G.S., Bureau of Land Management, National Park Service, Federal Aviation Administration, Alaska Department of Natural Resources, Department of Military and Veteran Affairs, Department of Community and Economic Development, and the Alaska Department of Transportation & Public Facilities (ASDMI, 2012).

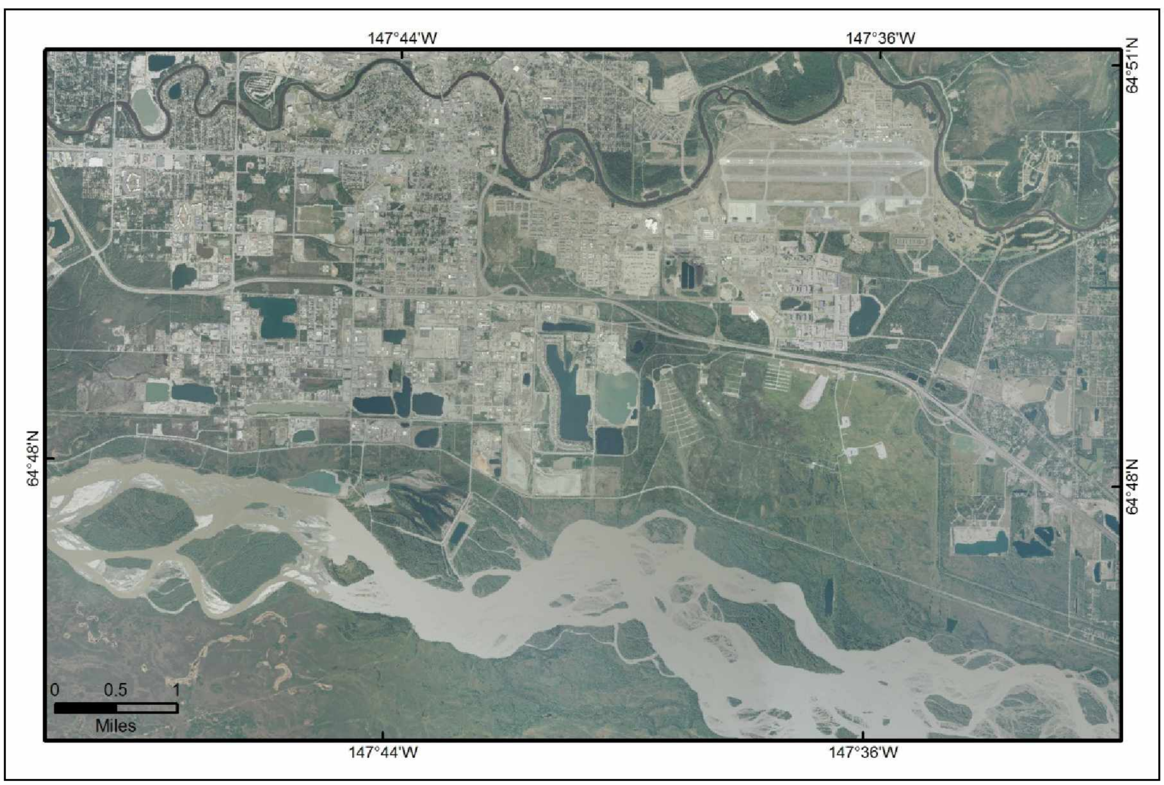

Figure 2.4: High resolution IKONOS imagery. This was used for detailed evacuation maps.

2012 Pictometry

In June 2012 Pictometry International collected aerial imagery of FNSB. These images were processed into a preliminary mosaic at 3.6 m resolution (Figure 2.5). This imagery was used as the main background layer for the map book.

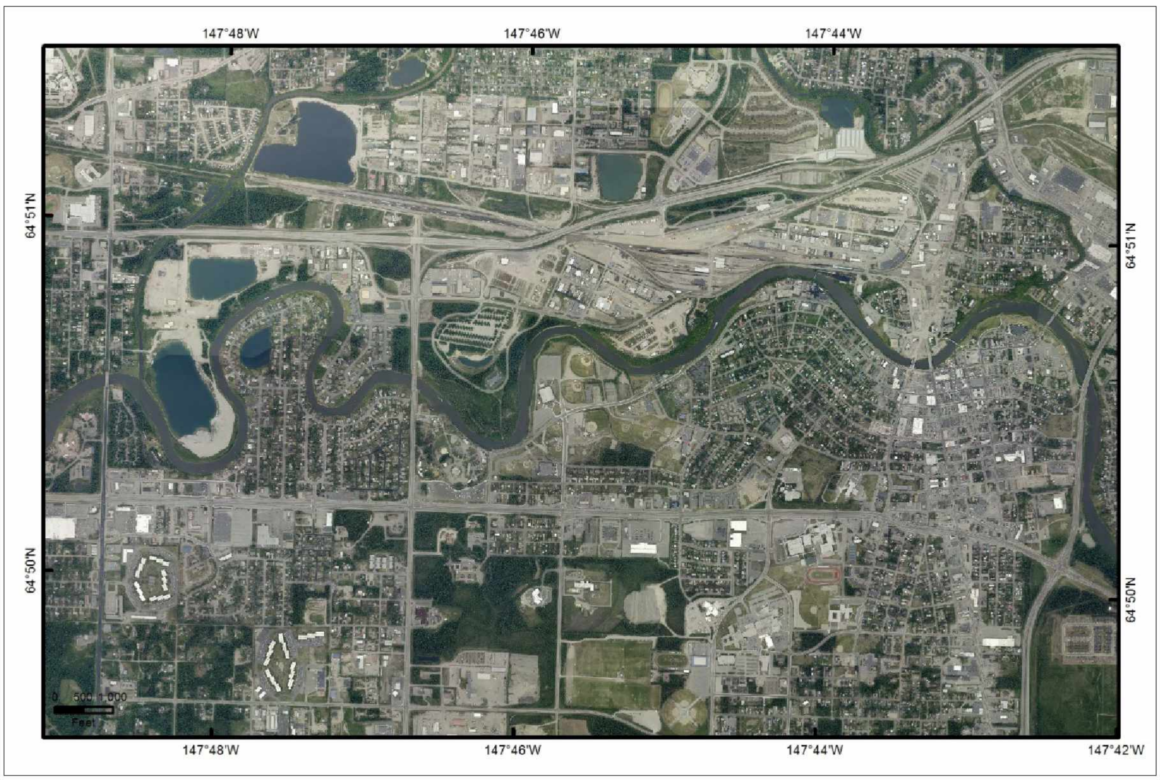

Figure 2.5: High resolution aerial photography by Pictometry.

2.2 GIS Data

While most of the datasets used in this project already existed, the data needed extensive editing. The analysis also required the compilation of many datasets into one clean and condensed geodatabase. The types and sources of the vector data used are described below.

FNSB Vector Data

FNSB provided several datasets for use in this research. The first dataset was a road centerline shapefile that contained centerlines for all known platted, non-platted, and private roads within the Borough. Original verified roads were extracted from parcel maps; these were then verified with current satellite and aerial photos. Any new roads found in the imagery were then added to the database. Imagery used for verification included Quickbird images from 2002, USGS digital orthophotography from 1998, and Landsat imagery from 2002 (FNSB, 2012). FNSB also provided a shapefile of all known address points, one point per house or building, and the location of all fire and police stations. Metadata for this information was sparse, but personal communications indicate the data was extracted from official platting records and verified with recent imagery. FNSB also provided shapefiles for various critical infrastructure and key resources including schools, airstrips, oil refineries, hospitals, the Alaska Pipeline, and local railroads. Most of this data is in the public domain and can be accessed through the Borough GIS data portal (FNSB, 2012) or the Alaska State Geospatial Data Clearinghouse (ASGDC, 2012).

Fairbanks Metropolitan Area Transportation System

The Fairbanks metropolitan area transportation system (FMATS) is a local multi-modal transportation system planning group that encompasses the urbanized parts of FNSB including the cities of Fairbanks and North Pole. They maintain a traffic shapefile used for modeling purposes that includes speed limits for most of the roads in the Borough (FMATS, 2012). This was the only known available dataset of speed limits for Borough roads. This dataset was provided by FMATS personnel in February 2011.

2010 U.S. Census Data

In 2010 the U.S. Census counted every individual living in the United States as mandated by Article one, Section two of the U.S. Constitution. Population totals were provided at the state, borough, city, tract, or block level, the block level being the smallest area from which population totals could be obtained. Population totals for the block level were downloaded in May 2011 as a spreadsheet (U.S. Census Bureau, 2012). A shapefile of the 2010 Census Blocks was downloaded from the U.S. TIGER/Line®Shapefiles webpage. The TIGER/Line®Shapefiles are spatial extracts of blocks, tracts, and other official geographic layers used by the U.S. Census Bureau (TIGER, 2012). Each block has a geographic entity code that corresponds to a code in the population totals spreadsheet. The table was combined with the block shapefile producing a shapefile of population on the block level. Figure 2.5 shows an example of these blocks for the city of Fairbanks.

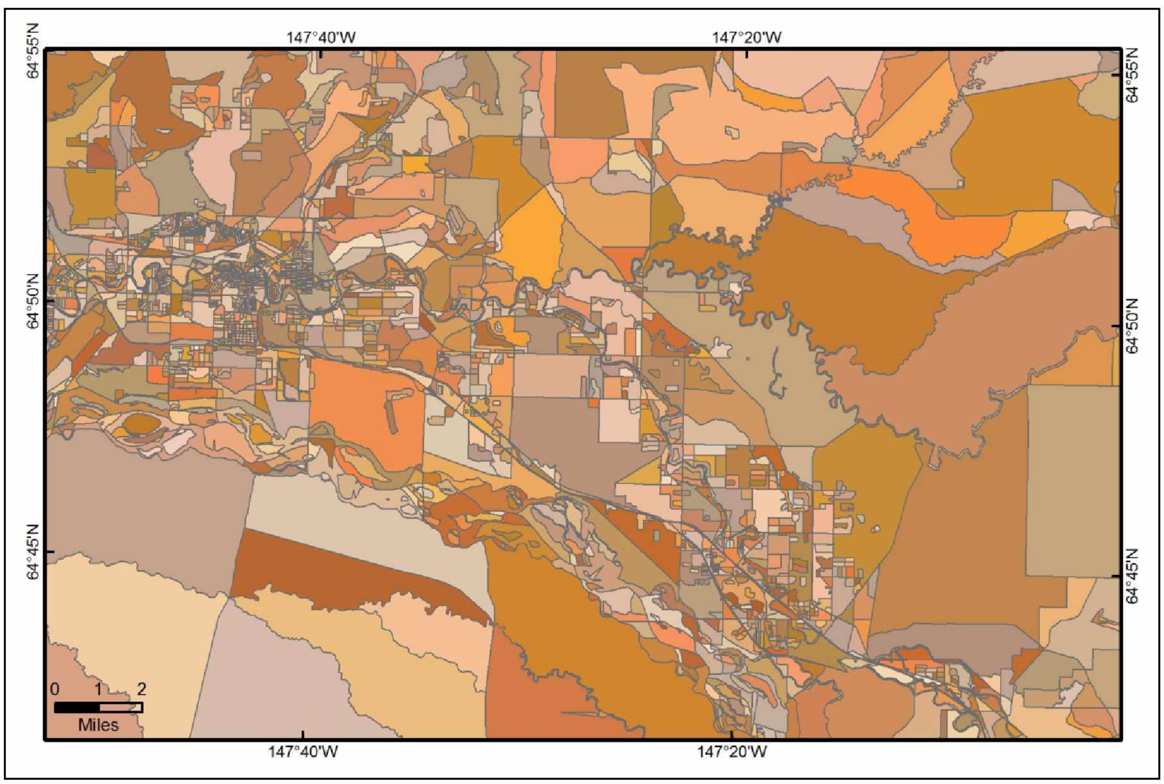

Figure 2.6: Sample of 2010 U.S. Census blocks shapefile. The blocks are generally smaller in high population density areas and larger in low population density areas. These blocks are symbolized with a random color scheme to show the variety of sizes and shapes.

Zones of Concern

The Alaska division of the U.S. Forestry Service working together with local fire departments have indicated certain zones within the Borough that are at a higher risk for wildfires based on vegetation, access, and density of human structures. A shapefile of these zones was provided by Forestry personnel in April 2012. Figure 2.6 shows what the shapefile of the zones looks like when overlaid on the FNSB road centerline shapefile. The zones came with three threat level classifications: high (green), very high (yellow), and extreme (red).

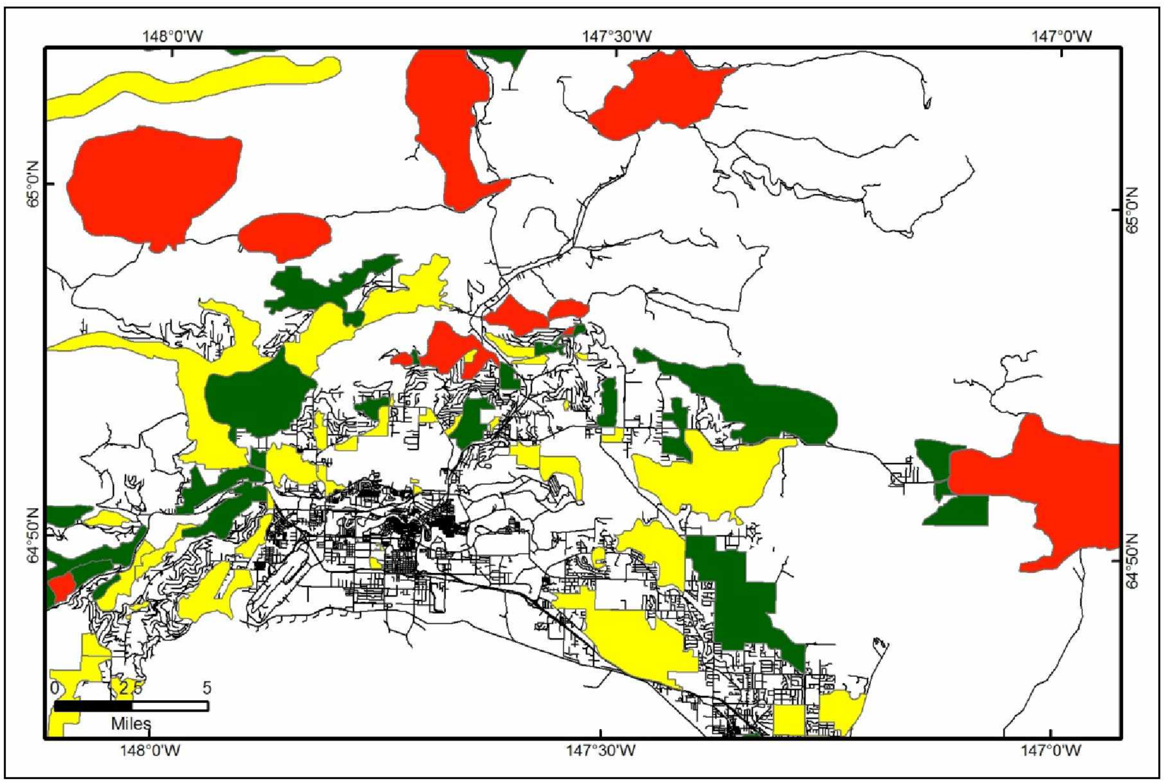

Figure 2.7: Sample of the U.S. Forestry "Zones of Concern". The zones are classified in three categories based on increased susceptibility to wildfires. The zones are: high (green), very high (yellow), and extreme (red).

2.3 Ancillary Data

In order to test the accuracy of the network analysis and its possible effectiveness as an emergency management tool, real emergency response calls from fire departments all over the Borough were compiled. 297 calls were provided by the City of Fairbanks Emergency Community Center in a comma-separated value (CSV) format. The calls took place from September 1, 2011 to November 29, 2011. This dataset required significant editing before it could be utilized.

The network analysis results were also tested against simulated call-time data collected under controlled conditions. A test area was chosen as a control area and thirty-two simulated calls were timed in October 2012. All simulated calls were driven during the daylight when the roads were dry. Each one started at the Chena Ridge fire station, station 42, and ended at the selected call address.

Chapter 3: Data Pre-Processing and Workflow

To carry out the analysis required for this research there were some key datasets that needed to be processed and combined into a geodatabase. This chapter describes the data attributes and steps followed for data pre-processing. Specific attribute names are explained in the table descriptions. However many of the codes in the attribute tables represent the Federal Information Processing Standard (FIPS) code for a specific region or area. FIPS codes are standardized government issued numbers that are used across all federal, state, and local levels in order to provide a standard way of identifying and using data (FIPS, 2012).

3.1 Workflow

All processing, tools and options discussed throughout this thesis were run using ESRI's ArcGIS Desktop 10 software with an ArcInfo License. The Network Analyst, Spatial Analyst, 3D Analyst, and Maplex extensions were also used. Data pre-processing involved a quality check on the road dataset, addition of slope information with the road dataset, inclusion of population dataset, and the collation of all data in a structured geodatabase. Figure 3.1 illustrates the pre-processing workflow.

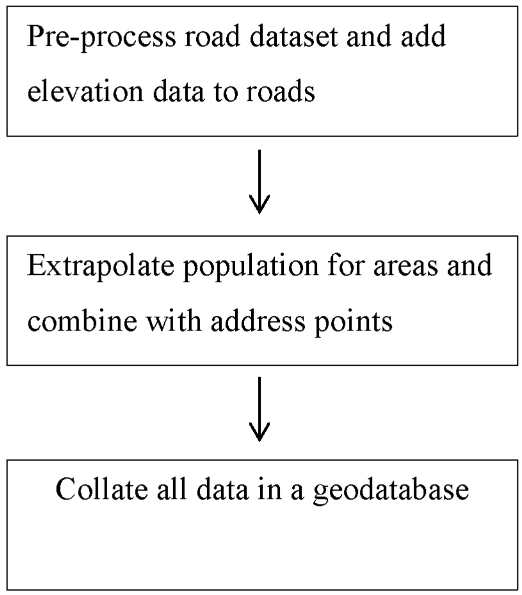

Figure 3.1: Pre-Processing workflow.

3.1.1 Pre-Processing Road Dataset

The first key dataset that was needed was a line shapefile of all the roads in the Borough that included road name, speed limit, and whether or not it was a one-way or a two-way road. Unfortunately, information on the type of road (pavement, dirt, gravel, etc.) was not available for all the road segments in the Borough. The road shapefile that the Borough provided included all necessary information except for speed limits and updated one-way road designations. This information was provided in another line shapefile by FMATS.

To combine the information in these two shapefiles the *Spatial Join* tool was used. The following settings for the tool were applied:

Target: FNSB road shapefile

Join: FMATS road shapefile

Operation: One to One

Match Operation: Closest

This successfully joined the information from the FMATS shapefile to the Borough shapefile. A topology was then built for the road shapefile to check for any gaps in the system, unnecessary overlaps, and other general errors.

To prepare the road shapefile for use in the network analysis it was necessary to calculate the slope of each road segment. To do this at an optimal level the roads were divided into 500 ft. segments. Smaller and larger road segment lengths were also tried, but it was found that much smaller segments overloaded the process and much larger segments did not provide the level of detail required for the analysis. First the *Densify* tool was used to add vertices every 500 ft. along each road segment. Then the *Split Line At Vertices* tool was used to cut each line segment at the vertices, while still retaining the data associated with the road. The field "Length_mi" was added and the length in miles was calculated using the *Calculate Geometry* tool.

ArcGIS 10 saw the addition of the *Add Surface Information* tool that is part of the 3D Analyst extension. This tool uses a surface, in this case the elevation raster datasets, to interpolate the heights of features. To do this, it takes the input raster and, as a background process, creates a temporary Triangular Irregular Networks (TIN), overlays the feature class on the TIN, and then estimates the elevation of each vertex (Li, et al., 2005). An average slope is then calculated based on the length of the segment over the TIN and that value is returned as a percent (ESRI, 2011). This method produces a higher quality slope estimate than the basic method of dividing the change in Y by change in X.

There was no uniform elevation dataset across the Borough so it was necessary to use several disparate datasets for calculating slope. The first data set used was the 30 m USGS DEM. The following parameters were used:

Input Feature Class: FNSB/FMATS combined road shapefile

Input Surface: 30 m USGS DEM

Output Property: AVG_Slope and Surface_Length

Method: Bilinear

Lengths were calculated for all road segments that fell within the confines of the 30 m USGS DEM. This was the first DEM used because it had the lowest resolution. This process was repeated multiple times, each time using a higher resolution dataset so that in the end the slope for each line segment was calculated using the highest resolution data available for the specific XY position. The order of the datasets used was: 30 m USGS DEM, 10 m USGS DEM, 3 m USGS DEM, and lastly the 1.2 m LiDAR DEM.

The result of this processing was a line shapefile that represented the centerlines of all the roads in the Borough with the following relevant fields:

RNAME: Full road name. Example: Richardson Hwy

ONEWAY: This option is set if the road has a one-way identifier

SPEED_LIM: Speed limit in miles per hour

SHAPE_LTH: Length of road segment in miles

AVG_SLOPE: Percent slope of line segment

3.1.2 Population Data

In order to have an estimate of how long an evacuation would take, or what resources it would use, it is important to know how many people are in an area. In this study the population values from the 2010 U.S. Census were combined with the number of address points in an area to estimate the average number of people per house. Population and housing unit totals for every census block in FNSB were merged with the census block shapefile. Before this data could be used, it was necessary to add a column to the population spreadsheet and then calculate a unique identifier that matched the block shapefile. These two files were then merged in ArcMap.

To combine the population with the address points that FNSB provided, the points were spatially assigned into their respective census blocks. The average number of people per structure was computed by taking the total population number for a block and dividing it by the number of structures. For example, if there was a total of 50 people in a certain census block and 20 structures in that block, the average population number assigned to every structure in that block would be 2.5. The step-wise process on how to merge the census data and then derive an average person per house is presented in Appendix B.1.

Tables 3.1, 3.2, and 3.3 are examples of the original attribute tables for the census block shapefile, the population data, and the final attribute table for the block shapefile after processing, respectively.

Table 3.1: Example table of the 2010 Census block polygon shapefile. STATEFP, COUNTFP, TRACTCE, and BLOCKCE are all the FIPS identifiers for the state, county, tract, and block number that the census used. GEOID10 is a unique identifier that combines the state, county, tract, and block FIPS codes into one field. NAME is the written text form of the block number.

STATEFP	COUNTYFP	TRACTCE	BLOCKCE	GEOID10	NAME
02	090	001900	3063	020900019003063	Block 3063
02	090	001900	3119	020900019003119	Block 3119
02	090	001900	3133	020900019003133	Block 3133
02	090	001900	1042	020900019001042	Block 1042
02	090	001200	2025	020900012002025	Block 2025

Table 3.2: A partial subset of the table showing 2010 Census population data. GEO is the full written identifier for each block. REGION, DIVISION, COUNTY are the FIPS codes. POP is the estimated population that the census collected for that block.

GEO	REGION	DIVISION	COUNTY	POP
Block 1000, Block Group 1, Census Tract 1, Fairbanks North Star Borough, Alaska	4	9	090	0
Block 1001, Block Group 1, Census Tract 1, Fairbanks North Star Borough, Alaska	4	9	090	0
Block 1002, Block Group 1, Census Tract 1, Fairbanks North Star Borough, Alaska	4	9	090	33
Block 1003, Block Group 1, Census Tract 1, Fairbanks North Star Borough, Alaska	4	9	090	0
Block 1004, Block Group 1, Census Tract 1, Fairbanks North Star Borough, Alaska	4	9	090	0

Table 3.3: Example of final attribute table for the block polygon shapefile. GEOID10 is the unique block identifier that was used to join everything. POPULATION is the original census population that was joined from the spreadsheet to the block shapefile. ADDRESSPTS is the frequency, or total number of address points per block. ADDPOP is the average population number that was calculated.

GEOID10	POPULATION	ADDRESSPTS	ADDPOP
020900019003063	3	0	3.00
020900019003119	0	1	0.00
020900019003133	3	5	0.60
020900019001042	0	0	0.00
020900012002025	9	11	0.82
020900012001042	41	40	1.03
020900012001032	30	13	2.31
020900012001030	17	5	3.40

The calculations produced a census block-level polygon shapefile that had the type of information shown in Table 3.3. This information was added to the individual address points. To assign the address points into their respective census blocks, each point was assigned a block ID, in this case the ID that was provided by the census in the form of the “GEOID10” field, using a *Spatial Join*. To transfer the new population average information from the block shapefile to the FNSB address point shapefile the *Join Field* tool was used. This imported the average population per house column, “ADDPOP” field listed in Table 3.3, into the address point shapefile. This method produced a point shapefile that included every known address in the Borough and its average population per address. Figure 3.2 illustrates this concept.

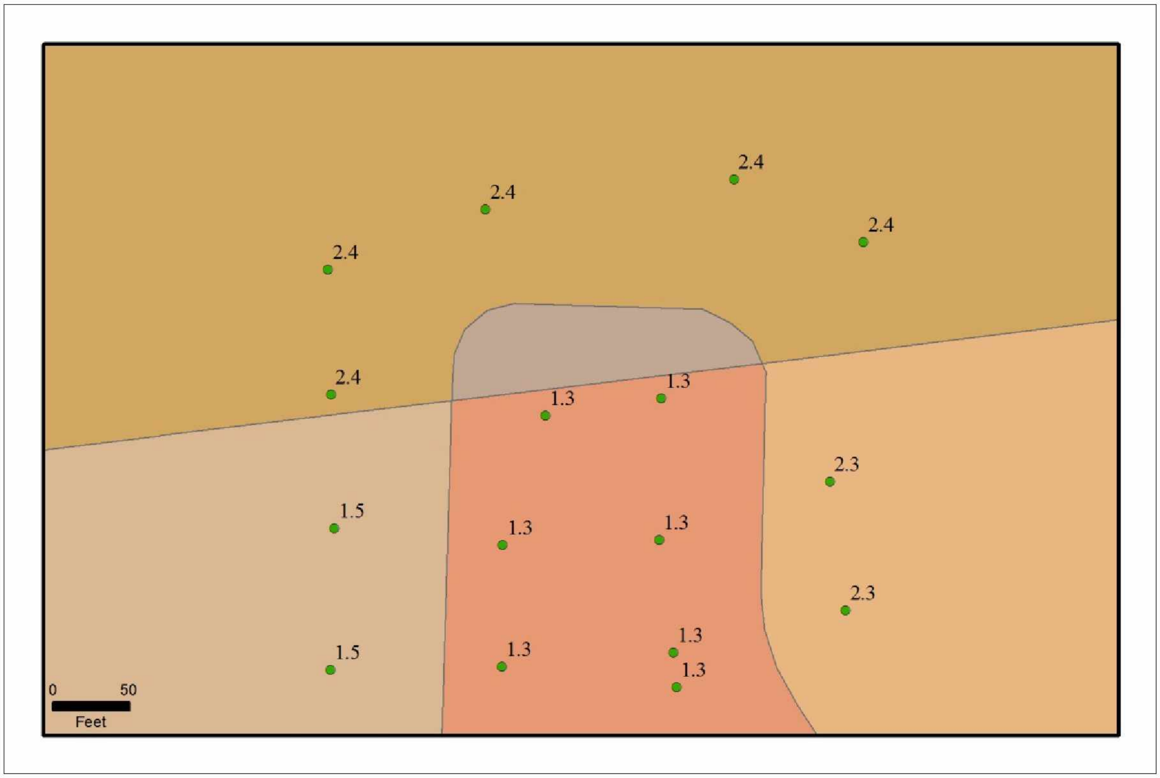

Figure 3.2: The steps to combine population with address points. Each colored polygon is a different census block, there are 5 census blocks shown. Each green dot is an address point. The number to the top-right of each dot is the average population that was estimated by dividing the population total for each census block by the number of address points in the block. That average was then assigned to each point. To calculate the total population for an evacuation zone, the average for each point in the zone was summated. The total population for the area shown would be 28.7.

3.2 Geodatabase

The previous sections discussed the development of two key shapefiles, a road centerline shapefile and an address point shapefile that includes estimated population per address. These two shapefiles were imported as feature classes into a file geodatabase in ArcCatalog. A file geodatabase was chosen over a personal geodatabase because it allows multiple people to access the different data sets and can have a maximum storage capacity of 256 TB. A personal geodatabase can only be accessed by one person at a time and has a maximum capacity of 2 GB (ESRI, 2012a). Because this will be a geodatabase that the Borough will continue to use and add onto, it is necessary that multiple people be able to access it and that it has sufficient storage for future needs. A file geodatabase also allows check-in/check-out and one-way replications. This geodatabase was used for all future processes, including the network analysis and evacuation planning discussed in subsequent chapters.

Chapter 4: Network Analysis

One of the major components of this research was the development of a network analysis that takes into account the weather and road conditions that are particular to FNSB. A network is a set of elements that can be connected and then the flow between those elements can be analyzed (Vonderohe, 1993; ESRI, 2012b). Network analysis has been used extensively in mapping traffic patterns and making signal timing more efficient (Simkowitz, 1990; Dowling, 1999). It can also be used in watershed analysis (Lizama Rivas and Koleva, 2008), and in creating efficient delivery routes for merchandise. In the context of emergency response, network analysis can enable emergency managers to analyze a road network and, among other things, determine the most efficient service areas surrounding a fire station (Abdel-Aty et al., 1995; Yang et al., 2010; Yingying et al., 2010). For example, it is possible to determine service areas by length, by how many roads or addresses are within a 1.5 mile area, or by how long it would take a fire apparatus to arrive at a certain neighborhood. In this research several tools within the *Network Analyst* extension in ArcMap were utilized.

A large body of recent literature exists that examines various ways to set up a basic road network and new algorithms to model emergency response vehicles and traffic flows (e.g. Yang et al., 2005; Xiang et al., 2009; Mladineo et al., 2011). This research uses the GIS processing tools, based upon Dijkstra's algorithm (Dijkstra, 1959), to create a network that would reflect site specific conditions.

There have been several case studies examining the use of network analysis applied to improving emergency response that account for several different variables in estimating response times (Gheorghe and Vamanu, 1999; Thirumalaivasan and Guruswamy, 1999; Cova and Johnson, 2003; Price, 2008). These variables include: speed limit vs. actual speed of a fire engine, slope of the road, time it takes to traverse an intersection, and general estimations without taking any of these factors into account (Price, 2009; Zieler, 2010). This research used these variables as a starting point to build a network that is suitable for FNSB roads and could be tested against actual emergency fire call times from the Borough.

4.1 Workflow

The road shapefile generated using the methods described in Chapter 3 had speed limits for each of the roads within the Borough, the percent slope every 500 ft., and the length of each road in miles. These three fields formed the basis for the network. To test the effect of different penalties for slope and turns, other fields were added. Figure 4.1 is a generalized workflow for the network analysis carried out in this study.

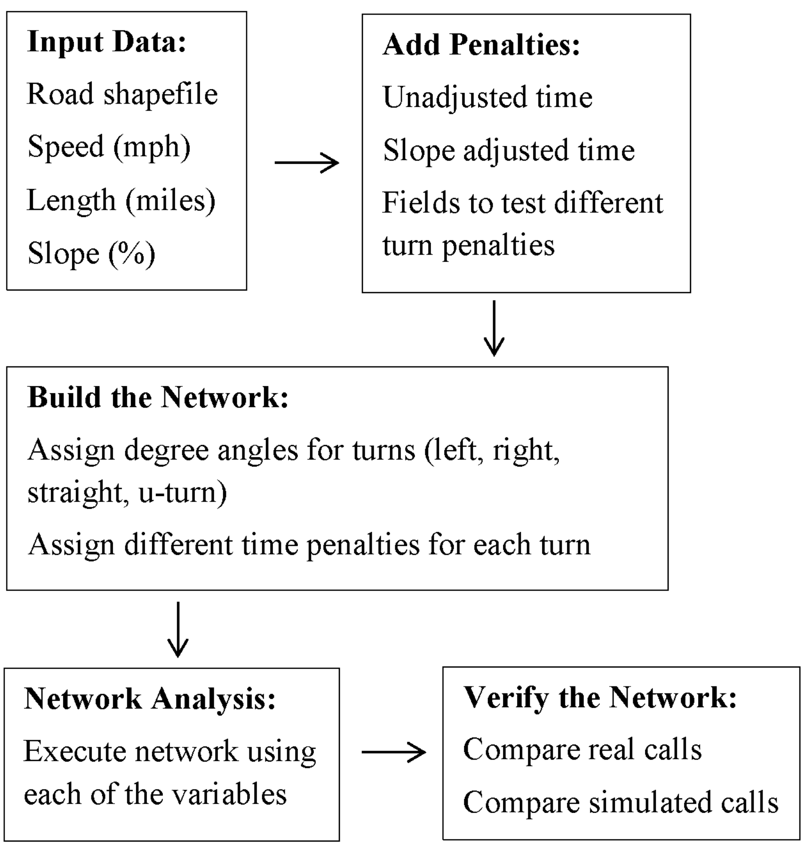

Figure 4.1: General network analysis workflow for FNSB.

4.1.1 Preparing the Penalty Fields

The first step in preparing the roads to be used in the network was to calculate the various fields that would be tested (Table 4.1). The first field, "MinUA", represents the unadjusted time in minutes that an engine would take if the road traversed was assumed to be flat, with no turns. The formula for this field is as follows:

$$MinUA = Length\_mi * (60/Speed\_mph)$$

The next field, "SlopeAdj", was created to account for how much longer an engine would take going up a steep slope than a gentle one. The method demonstrated by Price (2008) was used:

$$SlopeAdj = 1 + (Slope/10)^2$$

Adding 1 to the $(Slope/10)^2$ ensured that the resulting decimal value was greater than one. The slope adjustment field was multiplied by the unadjusted time field to create a new travel time, "MinS", which accounts for delays (penalties) on roads with a certain slope:

$$MinS = SlopeAdj * MinUA$$

Using this method, the predicted travel time for an engine traversing a road with a 0% slope grade would be the same as the unadjusted travel time, and a 5% slope grade would be 1.25 times greater than the unadjusted travel time. The travel time on a road with a 10% slope grade would take twice as long as the unadjusted time.

MinUA is the control network, the one that is based upon the speed limit and length of a road and does not add any penalties. MinS adds a penalty for the slope of the road. All other network options used the MinUA and MinS fields as the base information and then added time penalties to that base. To test the effect of different turn penalties on the network it was necessary to create four more fields. "MinUA_T1" and "MinS_T1" are based off of MinUA and MinS, respectively, but they add a low time penalty for each turn along a route. "MinUA_T2" and "MinS_T2" are again based off MinUA and MinS, but they then include a high time penalty for turns along a route. Table 4.1 lists the relevant fields and their corresponding formula. Details of the turn penalties are described in section 4.1.2.

Table 4.1: Slope and time fields calculated before the network analysis.

Field Name	**Description**	**Formula**
MinUA	Unadjusted time field in minutes	(60/speed_limit_mph) * length_mi
SlopeAdj	Slope-based multiplier	$1 + (\text{Slope}/10)^2$ (Price, 2008)
MinS	Slope adjusted time field in minutes	(MinUA * SlopeAdj)
MinUA_T1	Field for unadjusted, low turn penalty	= MinUA + low penalty for turns
MinUA_T2	Field for unadjusted, high turn penalty	= MinUA + high penalty for turns
MinS_T1	Field for slope adjusted, low turn penalty	= MinS + low penalty for turns
MinS_T2	Field for slope adjusted, high turn penalty	= MinS + high penalty for turns

4.1.2 Building the Network

With the road dataset and penalty fields set up, the actual network was built in ArcCatalog with the following settings: Use Model Turn Networks: Yes, Connectivity: End Point set, Model Elevation of Network: No.

When the different attributes for the network are set, the different time estimates for turns are also set. Four different turn penalties were assigned for each of the different kinds of turns. Turns were defined by the degree of change in the route. For instance, if an engine approached an intersection and deviated from the straight path between 30°-150° then that deviation was classified as a right turn. Figure 4.2 is a diagram of each possible turn and the range of degrees assigned to it.

MinUA and MinS were assigned turn penalties of zero seconds for each turn. MinUA_T1 and MinS_T1 were both assigned a turn penalty in the form of seconds for the following turn types: right – 2 sec, left – 5 sec, straight – 1 sec, and u-turn – 15 sec. MinUA_T2 and MinS_T2 were assigned higher turn penalties: right – 5 sec, left – 10 sec, straight – 2 sec, and U-turn – 30 sec. With the turn and slope penalties calculated, it was possible to run a total of six different network options (Table 4.2). This allowed for a range of network times to test against call times that would determine which option was the best fit for the FNSB area.

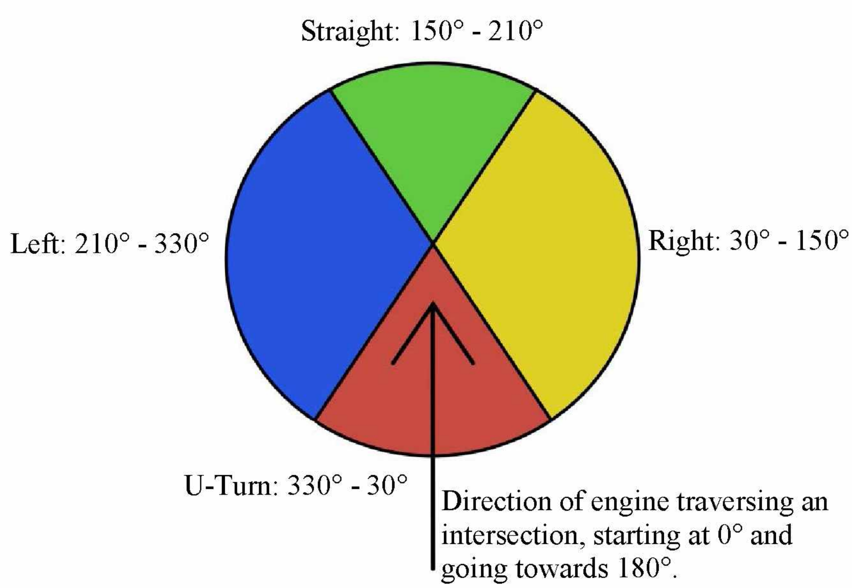

Figure 4.2: Diagram of angles used to determine the type of turn.

Table 4.2: Summary of the six network options that were tested.

Network Option	Description	Penalty (seconds)
MinUA	Unadjusted (UA), basic network	No turn penalties
MinUA_T1	Unadjusted network + turn penalty 1 (T1)	Left: 5, Right: 2 Straight: 1, U-turn: 15
MinUA_T2	Unadjusted network + turn penalty 2 (T2)	Left: 10, Right: 5 Straight: 2, U-turn: 30
MinS	Penalty assigned for slope (S)	No turn penalties
MinS_T1	Slope adjusted + turn penalty 1 (T1)	Left: 5, Right: 2 Straight: 1, U-turn: 15
MinS_T2	Slope adjusted + turn penalty 2 (T2)	Left: 10, Right: 5 Straight: 2, U-turn: 30

4.1.3 Network Analysis

FNSB has many fire stations. It was important to determine the extent of the primary service area for each station, and the travel time for an engine to reach a destination within its primary service area. Therefore, the locations of all fire stations were used along with all the network options described in section 4.1.2.

The *New Service Area* tool was used to create service areas for each fire station based on the different variables. In the new service area window all the fire stations were added as facilities. The network was then solved for the six different time options and the results saved. The network was also solved by just using the length field. This produced a service area map for each station based on miles instead of time. Each different time solve used a different attribute that was set up previously as its impedance value. For example, the first network solve was done with the following options set under the Analysis Settings:

Impedance: “MinUA”

Default Breaks: 3, 5, 8

Direction: Away from Facility

U-Turns at Junctions: Allowed at Intersections

These settings used the "MinUA" field as the impedance, the minute field that had not been adjusted for slopes and turns as the field used to calculate how long a segment of road would take to traverse. The default breaks set how large the calculated service area should be. In this example, since the impedance is a time field in minutes, the service area is broken into three minute, five minute, and eight minute response areas. The three, five, and eight minute breaks were chosen based on the Insurance Services Office (ISO) recommended response areas for a fire engine. When evaluating a community's public fire protection the ISO considers the distribution of fire stations. Generally the ISO rating states that an insured community should have a first-due fire engine within a 1.5 mile distance and a ladder service within 2.5 miles (ISO, 2007). The estimated time that these distances should take are 3.2 minutes and 4.9 minutes, respectively (ISO, 2007). The eight minute break is recommended by the National Fire Protection Association standard 1710 as the time by which all engines assigned to the call on the 1st alarm should arrive (NFPA, 2012). The direction option dictates that it should calculate the areas traveling away from each facility, i.e. an engine leaving a fire station that is heading towards a call destination. This process was repeated for each of the remaining time fields: MinUA_T1, MinUA_T2, MinS, MinS_T1, and MinS_T2. The network was then solved using the Length_miles field with breaks set at: 1.5, 3, and 5. This created a service area map for each station that showed 1.5 mile, 3 mile, and 5 mile areas around each station solely based upon road length (Figure 4.4). Each of these network areas was calculated for each fire station within FNSB. Figures 4.4 – 4.10 are maps of each of the different areas using the Chena Ridge Fire station. Appendix A has the complete set of service area maps for the entire Borough.

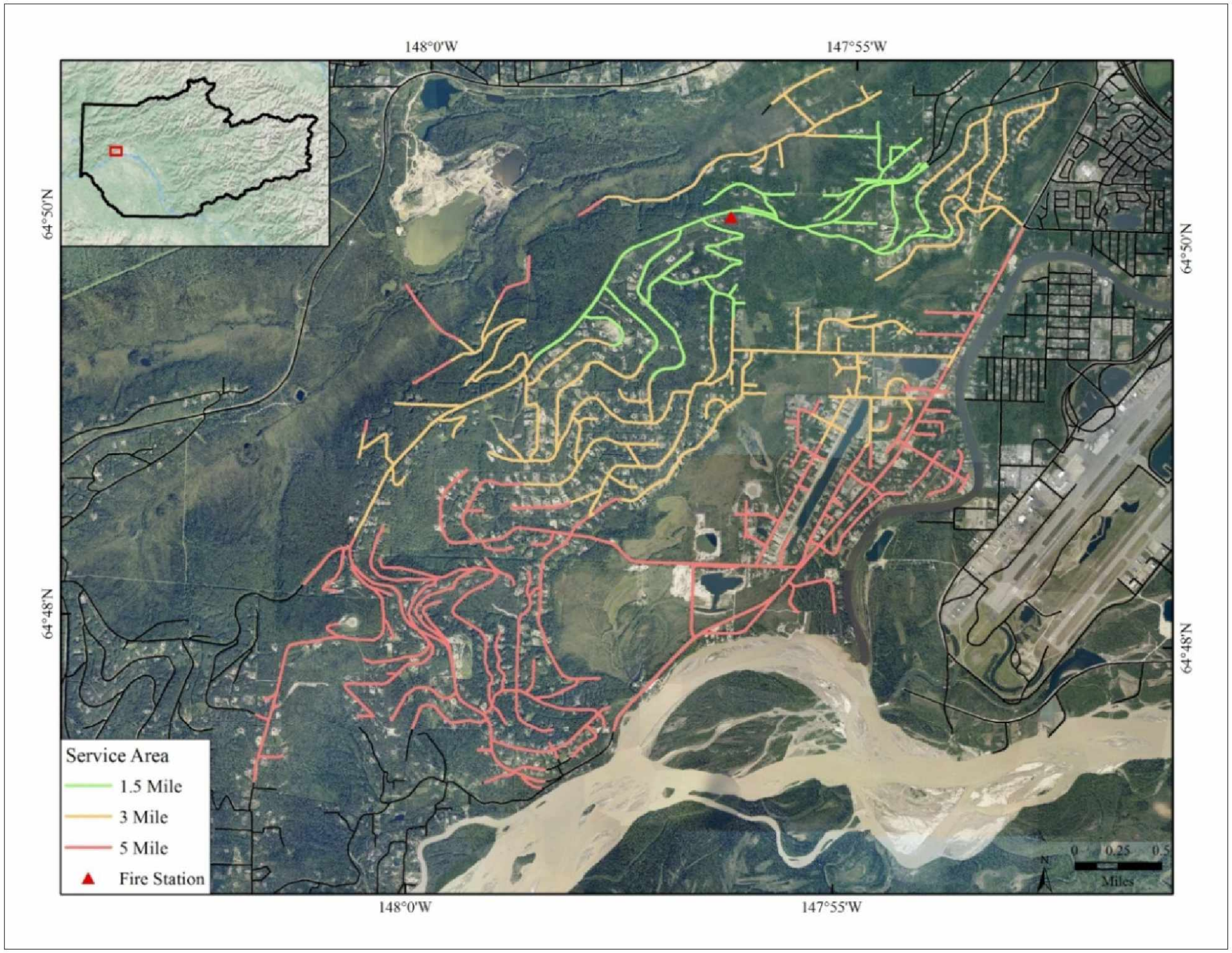

Figure 4.4: Service area based on length (miles). The area shown is of the Chena Ridge fire service area.

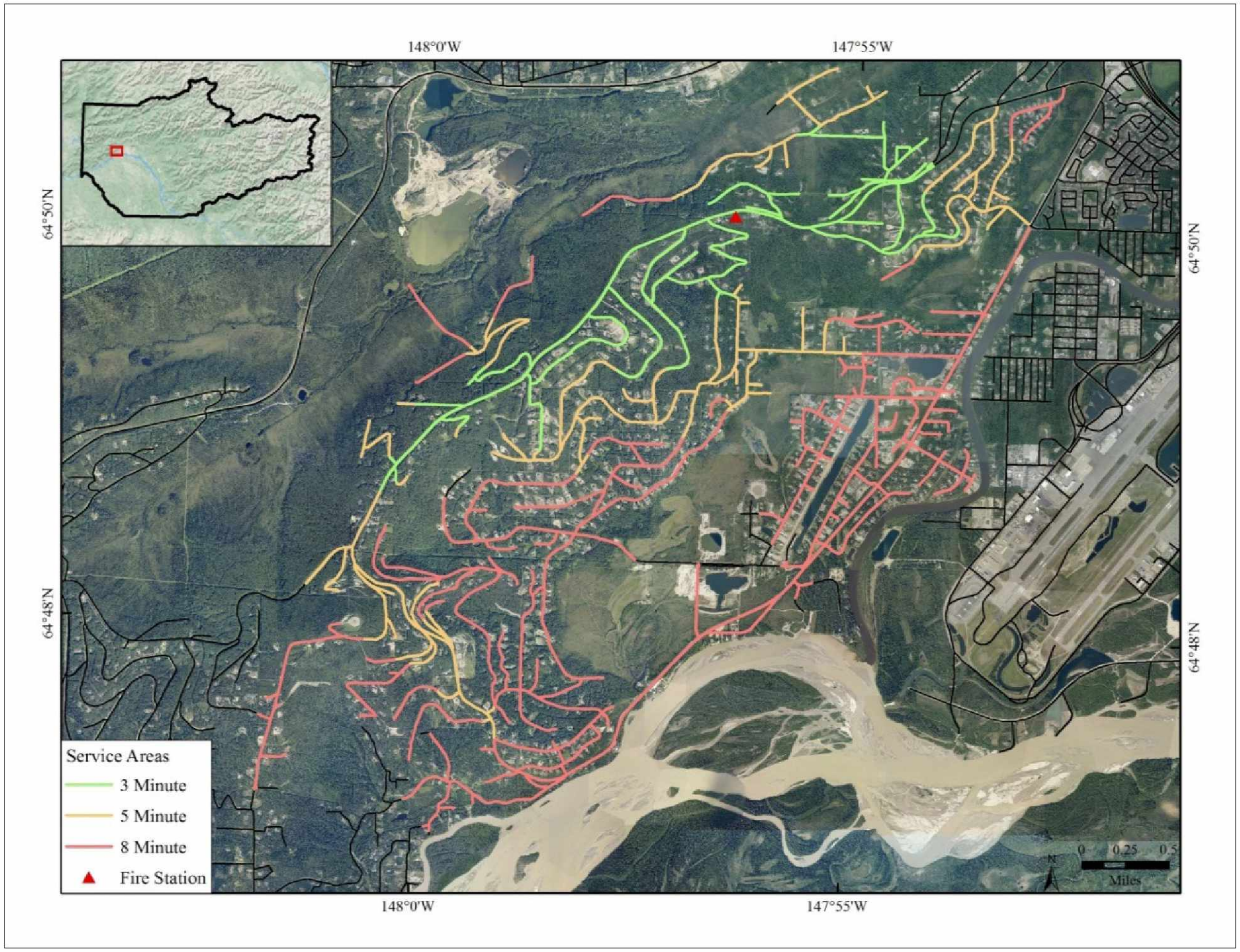

Figure 4.5: MinUA service area. This network used the unadjusted option that adds no time penalties.

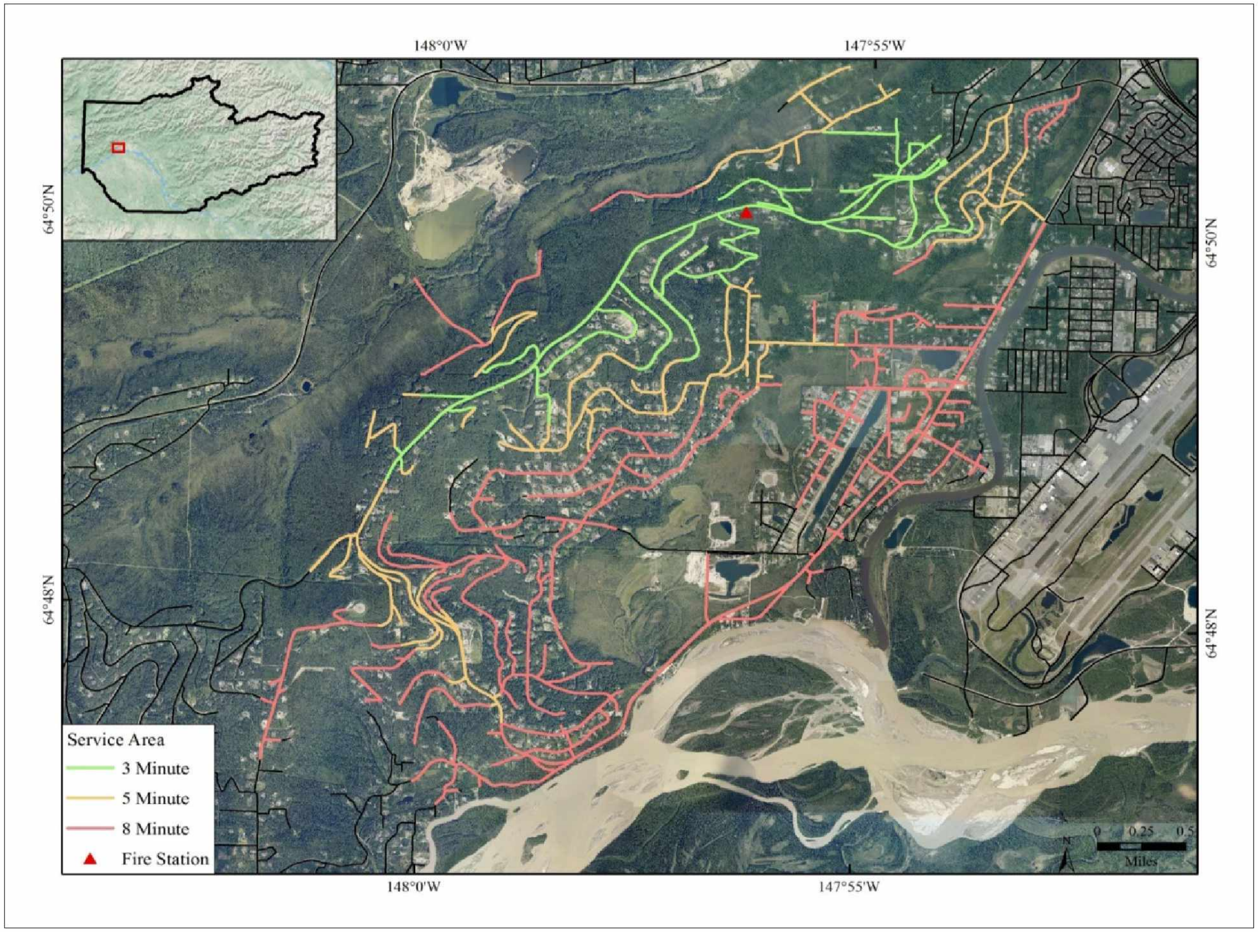

Figure 4.6: MinUA_T1 service area. This network used the unadjusted, time 1 network option. This option adds 2 second, 5 second, and 15 second time penalties for right, left, and u-turns, respectively.

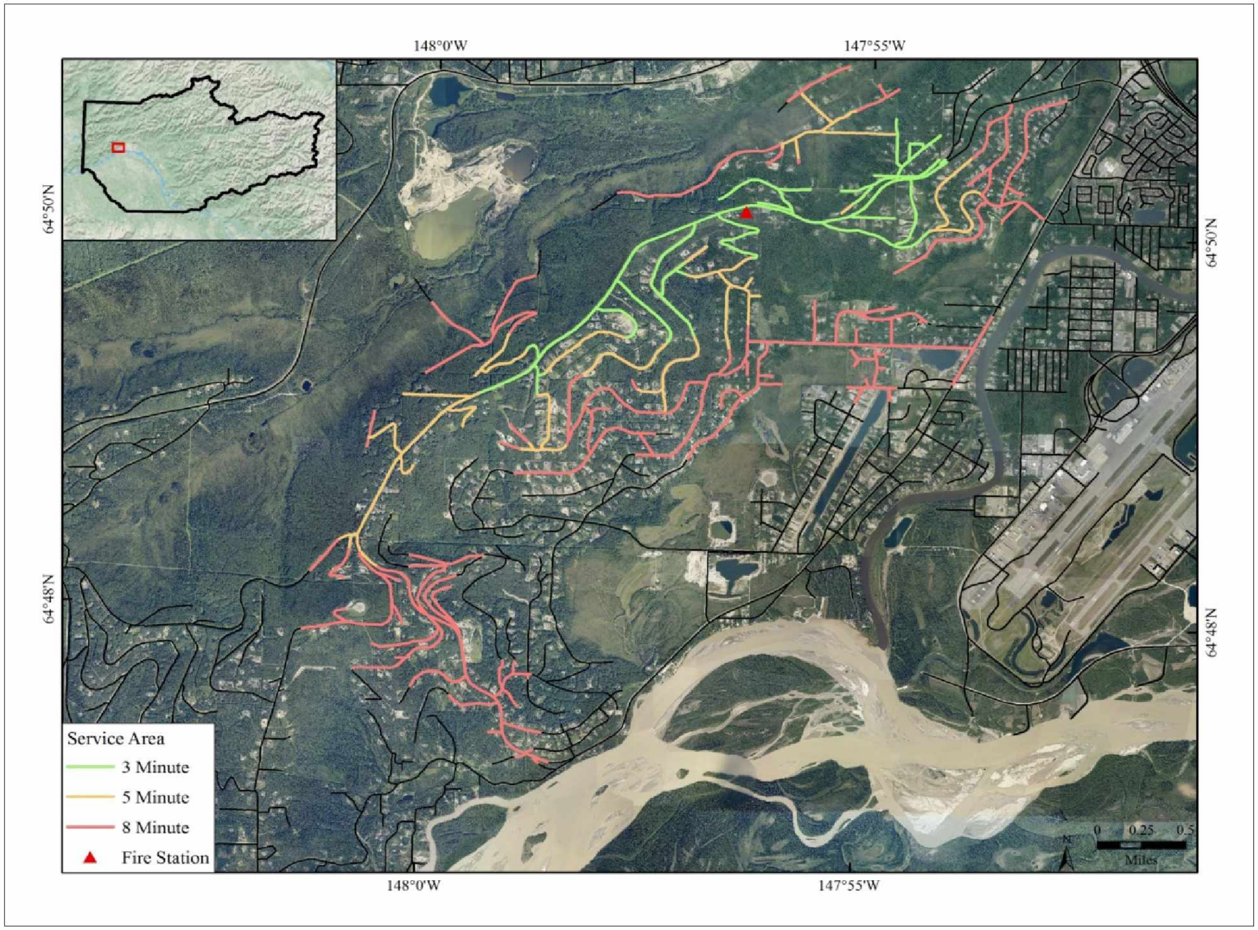

Figure 4.7: MinUA_T2 service area. This network used the unadjusted, time 2 network option. This option adds 5 second, 10 second, and 30 second time penalties for right, left, and u-turns, respectively.

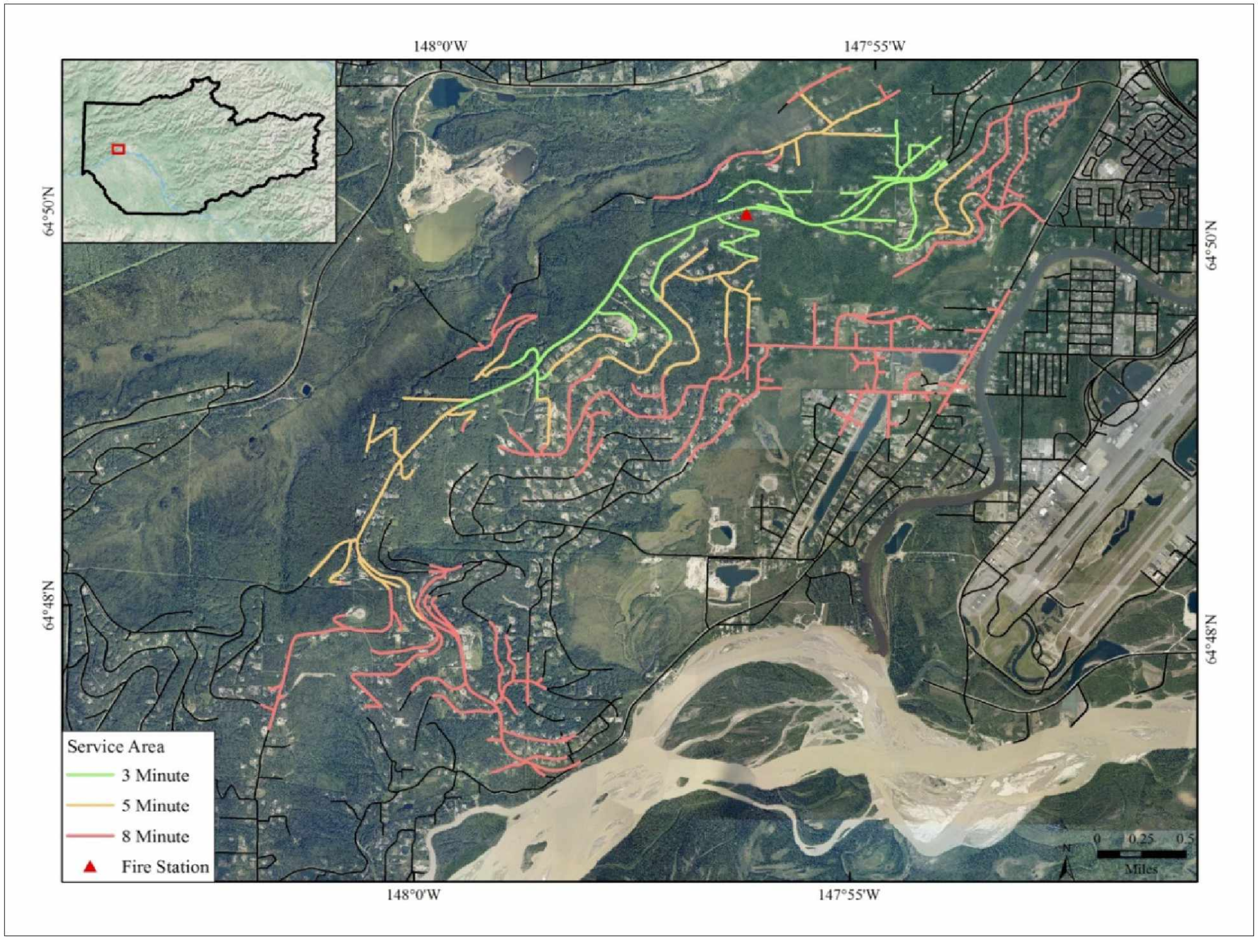

Figure 4.8: MinS service area. This network used the slope adjusted network option and adding no additional time penalties.

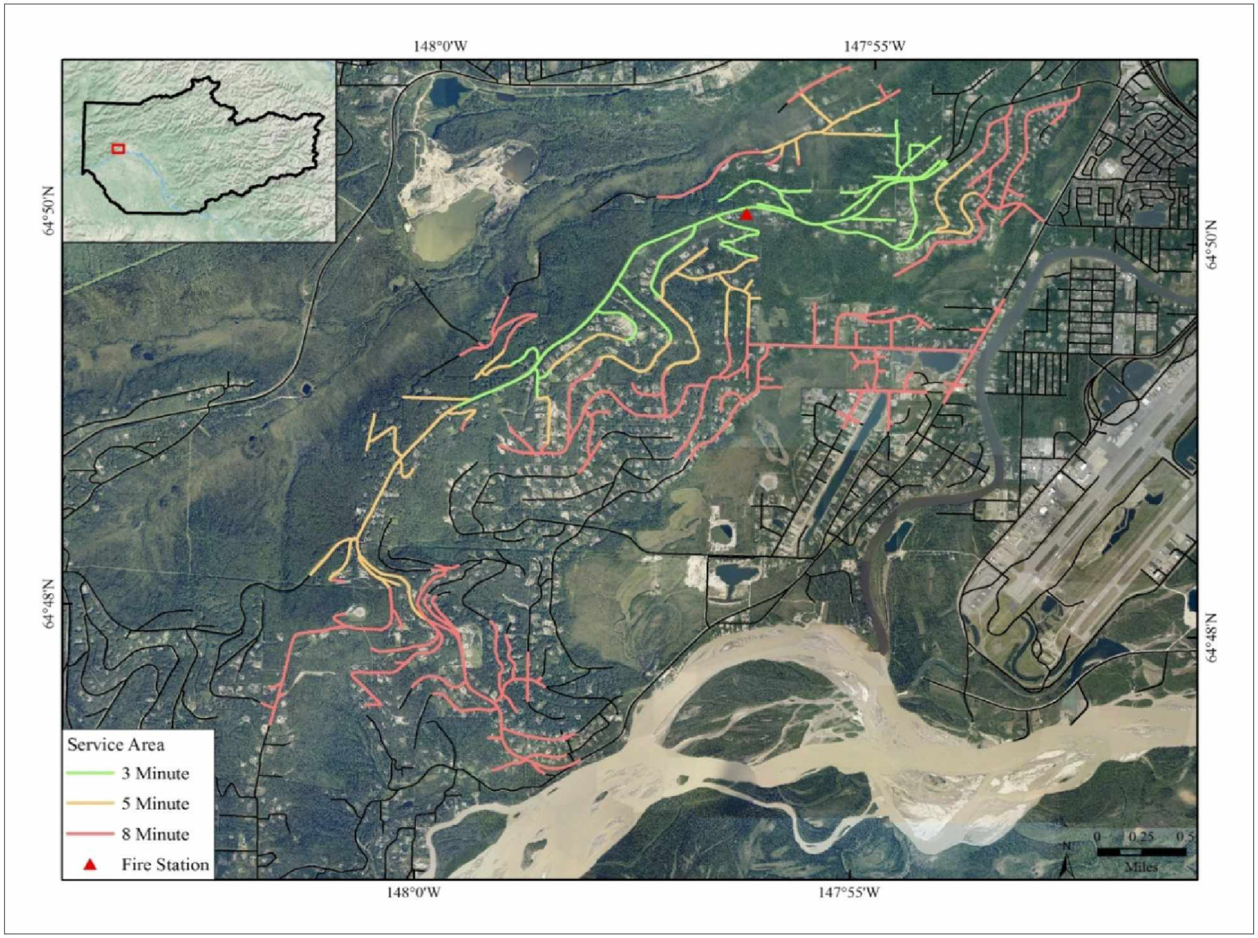

Figure 4.9: MinS_T1 service area. This network used the slope adjusted, time 1 network option. This option adds 2 second, 5 second, and 15 second time penalties for right, left, and u-turns, respectively.

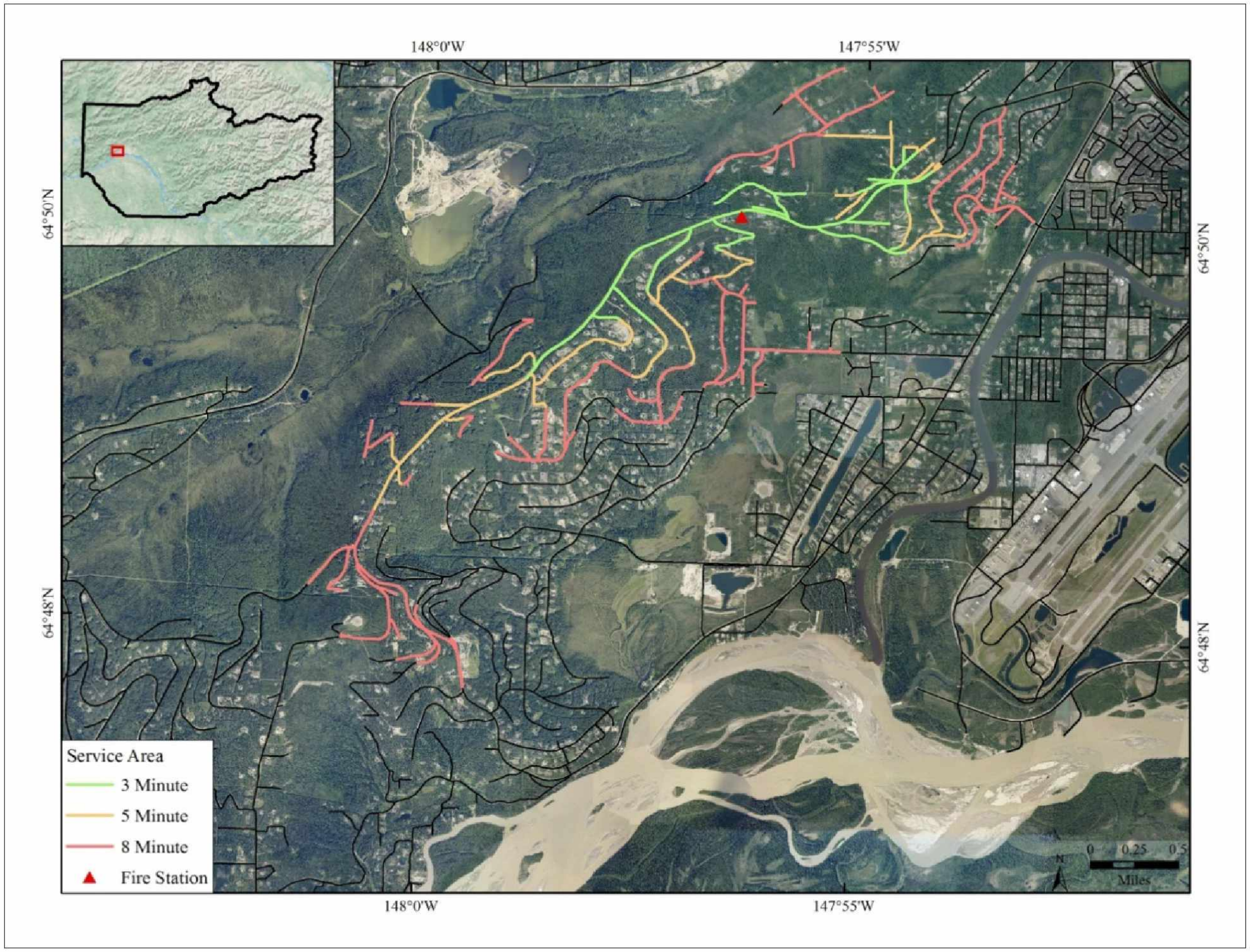

Figure 4.10: MinS_T2 service area. This network used the slope adjusted, time 2 network option. This option adds 5 second, 10 second, and 30 second time penalties for right, left, and u-turns, respectively.

4.2 Network Results

The network analysis produced seven different service area maps based upon the different network options: MinUA, MinUA_T1, MinUA_T2, MinS, MinS_T1, MinS_T2, and the length option for every station in FNSB. The next step in the analysis was to compare the different service area maps with call times to see which network configuration matched FNSB's actual response capabilities.

4.2.1 Real Calls

Total Calls

Call times from each fire service area were collected from the dispatch center. A total of 297 fire calls from September through November 2011 were used as a comparison. The calls were imported as a table and geocoded. Then a *Closest Facility Matrix* was run using the different network configurations that were used to solve for the different service areas. This process took each individual call and found the fastest route from the station to the call address using the same network options that were run to find the service areas: MinUA, MinUA_T1, MinUA_T2, MinS, MinS_T1, and MinS_T2 (the length network option was not included in this test). The result of this was six different possible times that the route could have taken, plus the one real time that the route took. The results were collated into one table and the outlier calls eliminated using a two sigma standard deviation value as the threshold for identifying outliers. After the outliers were discarded, the call total was 241. Each predicted time was then plotted against the observed time using a scatter plot.

After the predicted times were plotted against the real call times (Figure 4.11), an anomaly in the calls became apparent. There were a number of calls where all the network models estimated around a two minute travel time, but the actual travel times ranged from one to seven minutes. These specific calls were examined and it was determined that the actual call address had no specific address associated with it; the location given was just a road name. When these calls were geocoded, the nearest address point was assigned. The actual call times varied along that road, causing a wide range of response times. There were 26 such calls and these were also removed, giving a final call total of 215.

To measure the correlation between the call times and each of the predicted network times, two statistical values were examined. First, a linear regression line was applied to each scatter plot and the 1:1 relationship between the predicted times and the call times was examined. The closer the slope of the line was to 45°, the better 1:1 match. If the slope of the line was higher than 45° then the predicted call times generally over-estimated the observed call times. If the slope of the line was lower than 45° then the predicted call times generally underestimated the observed call times. The R^2 coefficient, also known as the coefficient of determination, was also examined. The R^2 coefficient indicates the strength and direction of a linear relationship between two variables. In this case, R^2 was used to examine the quality of the trend line fit between the observed and predicted times, making the assumption that the results were both normal and linear (Steel and Torrie, 1980). An R^2 value closer to 1.0 indicates that the regression line fit well, while an R^2 value closer to 0 indicates that the line fit poorly. The third value that was examined was the percentage of predicted call times that were within one minute of the actual call time for each of the networks. Figures 4.12 through 4.17 show the final scatter plots with the total observed call times plotted against each of the predicted network times; the R^2 value is shown on the scatter plot. To summarize the results, the R value (square root of R^2) for each network was compared (Table 4.3).

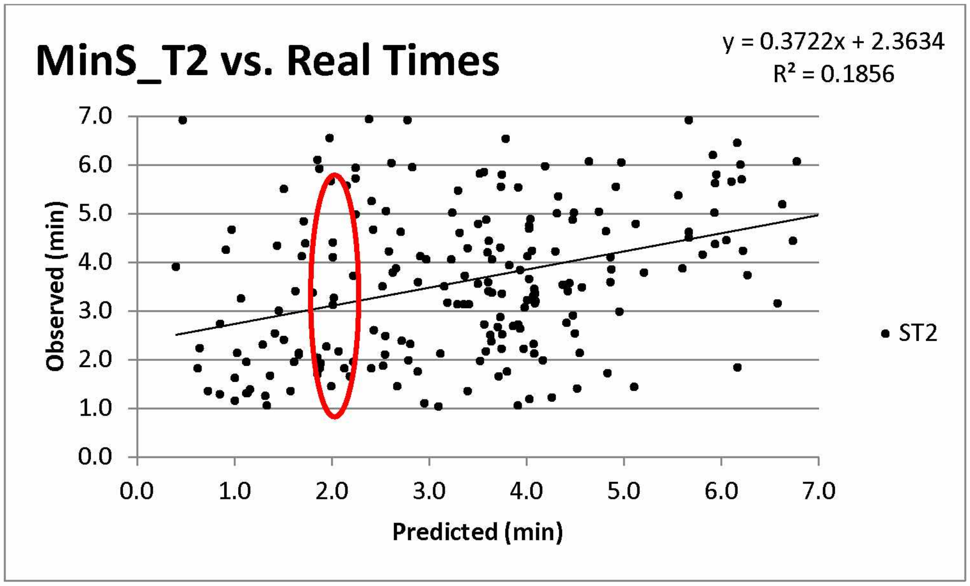

Figure 4.11: Observed call times vs. predicted call times with anomalies included. The red oval highlights the problem call times.

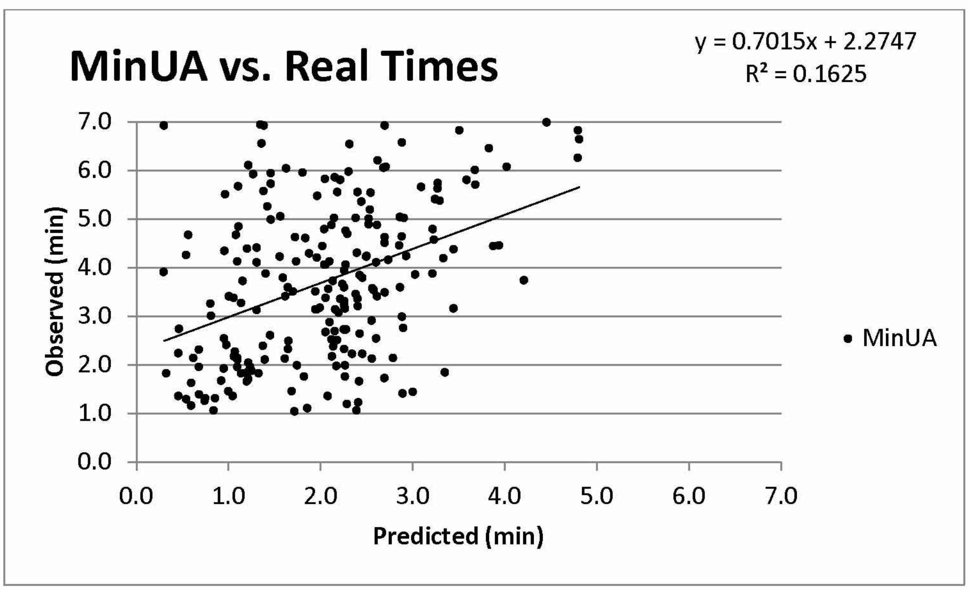

Figure 4.12: The unadjusted network call times vs. observed call times.

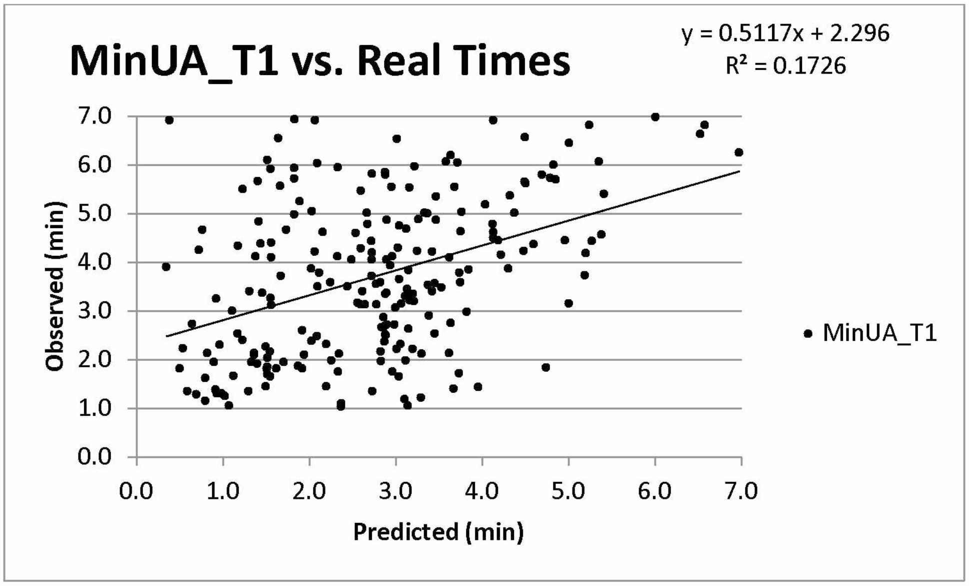

Figure 4.13: The unadjusted, time 1 network call times vs. observed call times.

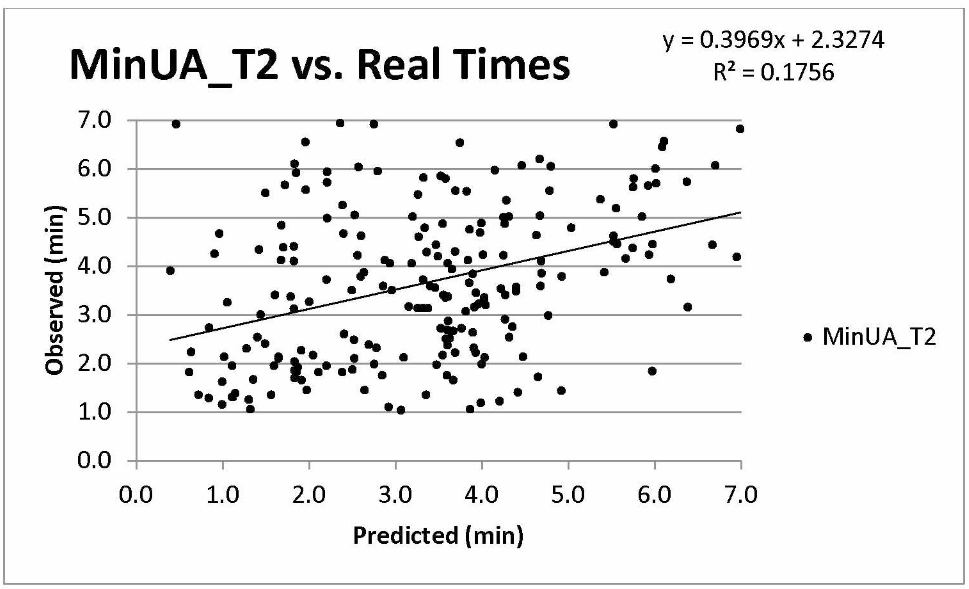

Figure 4.14: The unadjusted, time 2 network call times vs. observed call times.

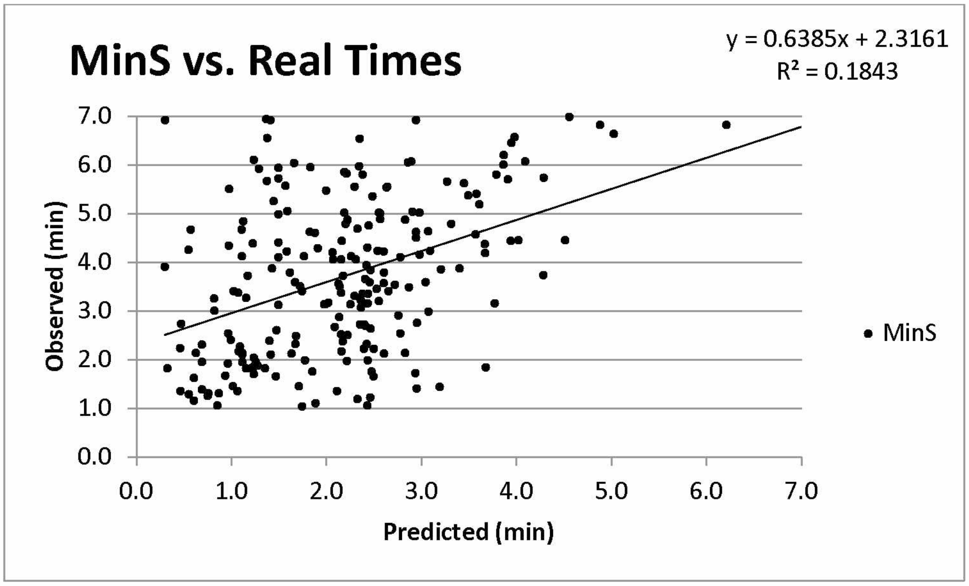

Figure 4.15: The slope adjusted network call times vs. observed call times.

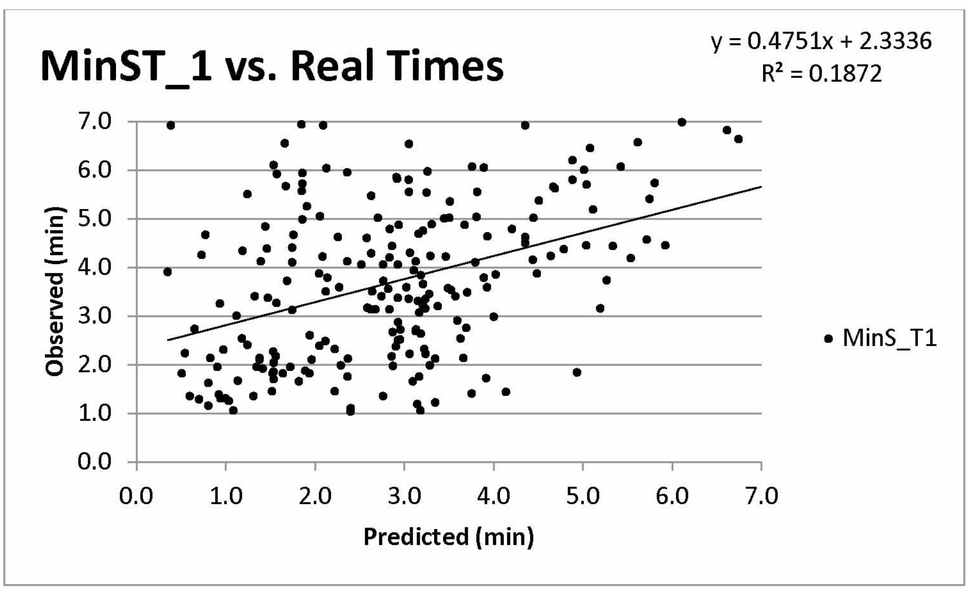

Figure 4.16: The slope adjusted, time 1 network call times vs. observed call times.

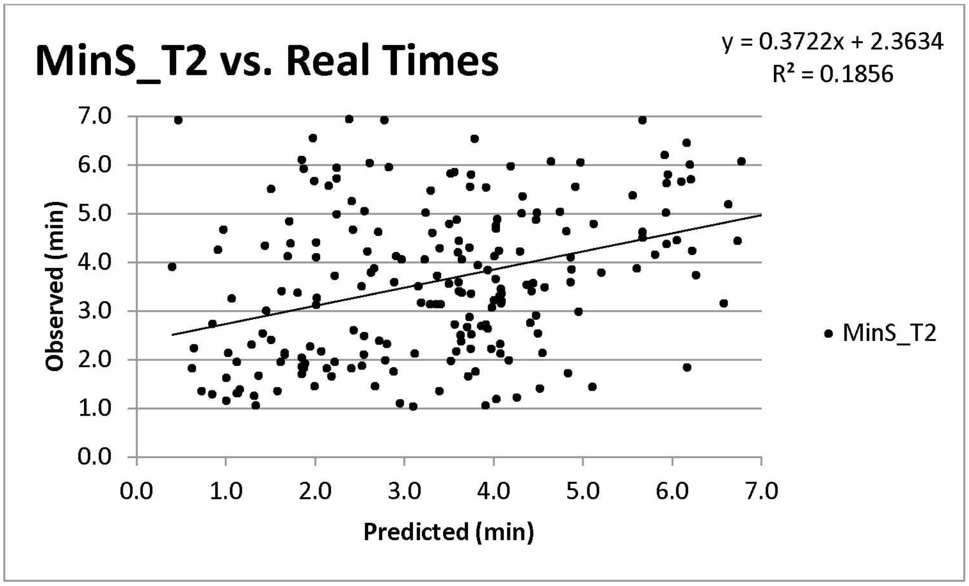

Figure 4.17: The slope adjusted, time 2 network call times vs. observed call times.

Seasonal Variables

The relationship between call time and seasonality was also considered. According to the National Weather Service in 2011 the first day of permanent snow for FNSB was October 17. The calls were then broken up into summer and winter designations, with any call that took place before October 17 designated as a summer call and any call October 17 or after designated as a winter call. There were 110 total calls in the summer category and 105 calls in the winter category. These two call groups were then re-plotted against each of the predicted routes to see if accounting for season improved network accuracy. Figures 4.18 through 4.23 are the summer time scatter plots and figures 4.24 through 4.29 show the winter time scatter plots. Table 4.3 summarizes the results of all the different scatter plots. Table 4.4 lists the percentage of predicted call times that were within one minute of the observed call time for each network.

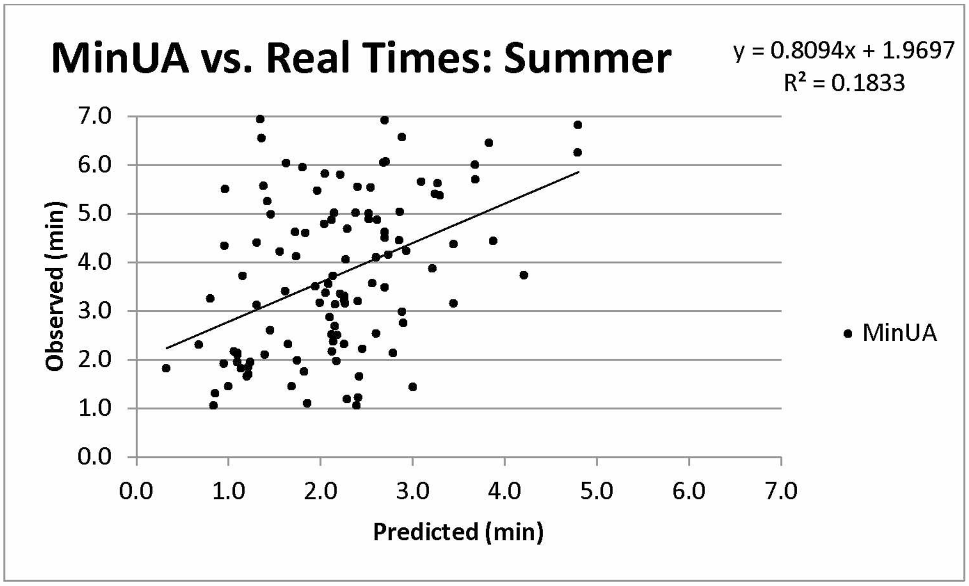

Figure 4.18: The unadjusted predicted call times vs. observed call times. These calls took place during the summer season.

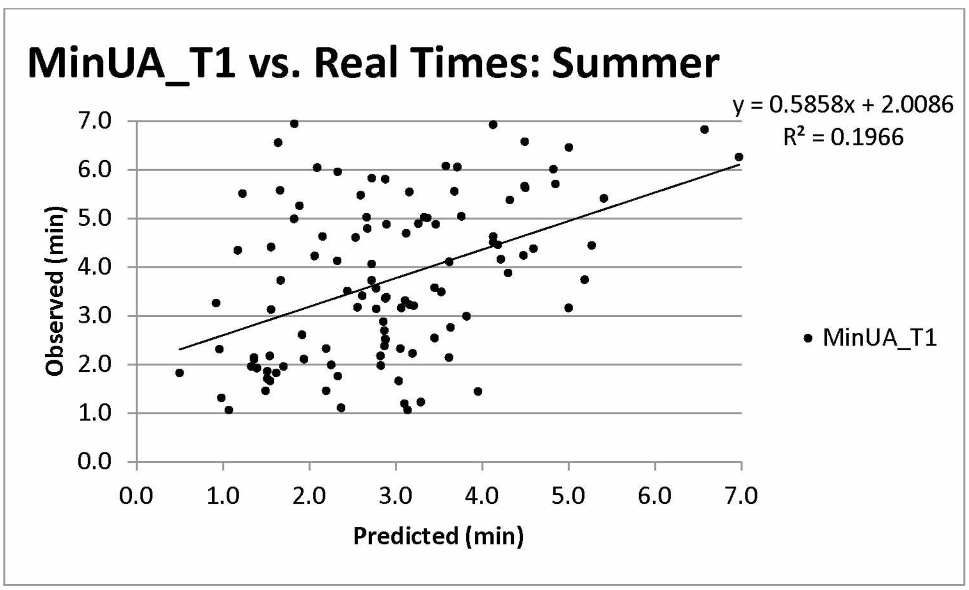

Figure 4.19: The unadjusted, time 1 network call times vs. observed call times. These calls took place during the summer season.

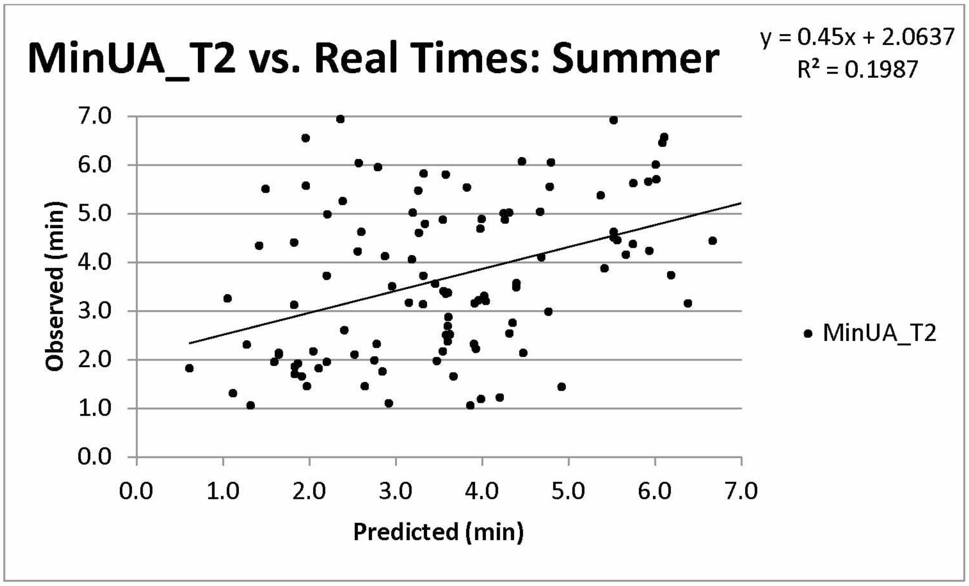

Figure 4.20: The unadjusted, time 2 network call times vs. observed call times. These calls took place during the summer season.

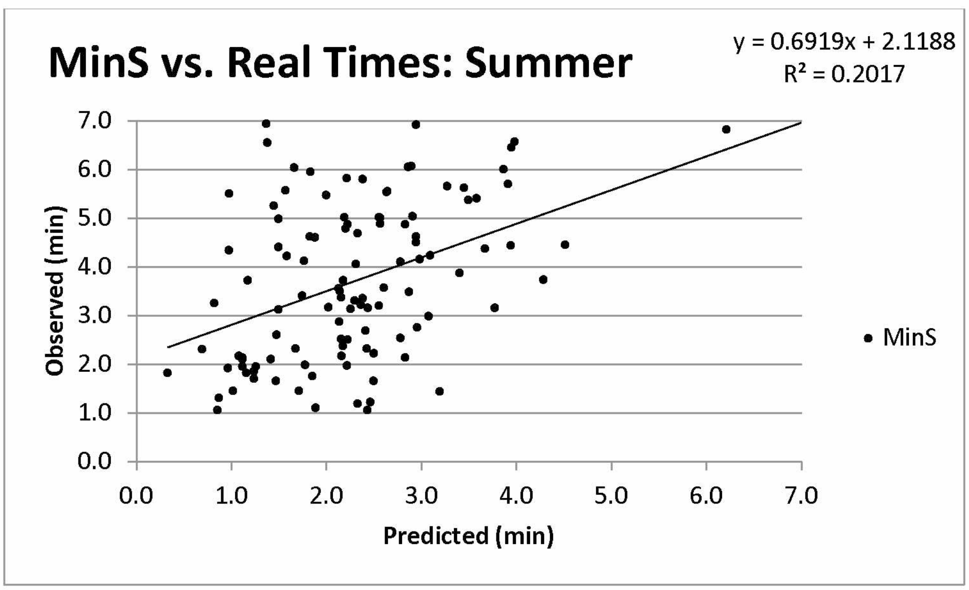

Figure 4.21: The slope adjusted network call times vs. observed call times. These calls took place during the summer season.

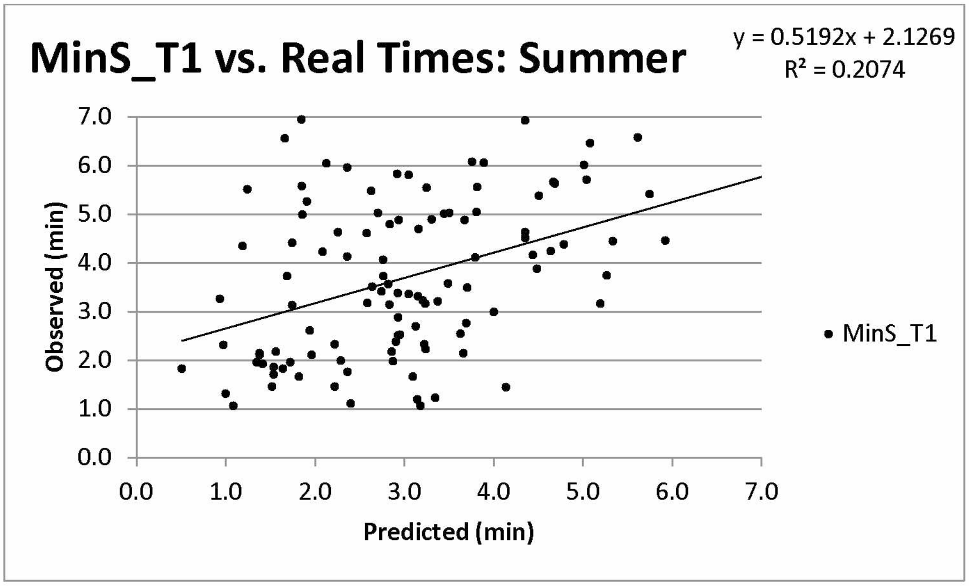

Figure 4.22: The slope adjusted, time 1 network call times vs. observed call times. These calls took place during the summer season.

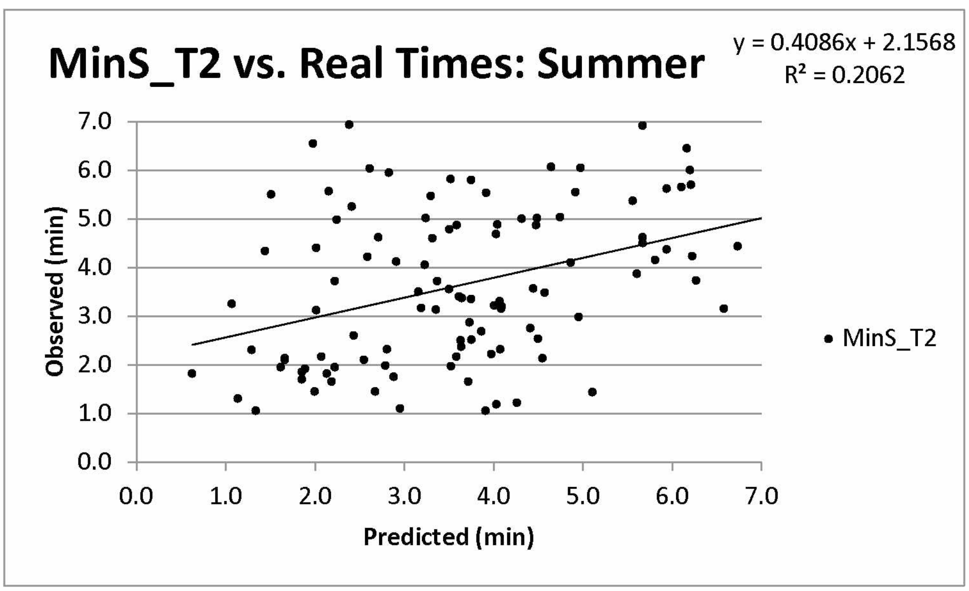

Figure 4.23: The slope adjusted, time 2 network call times vs. observed call times. These calls took place during the summer season.

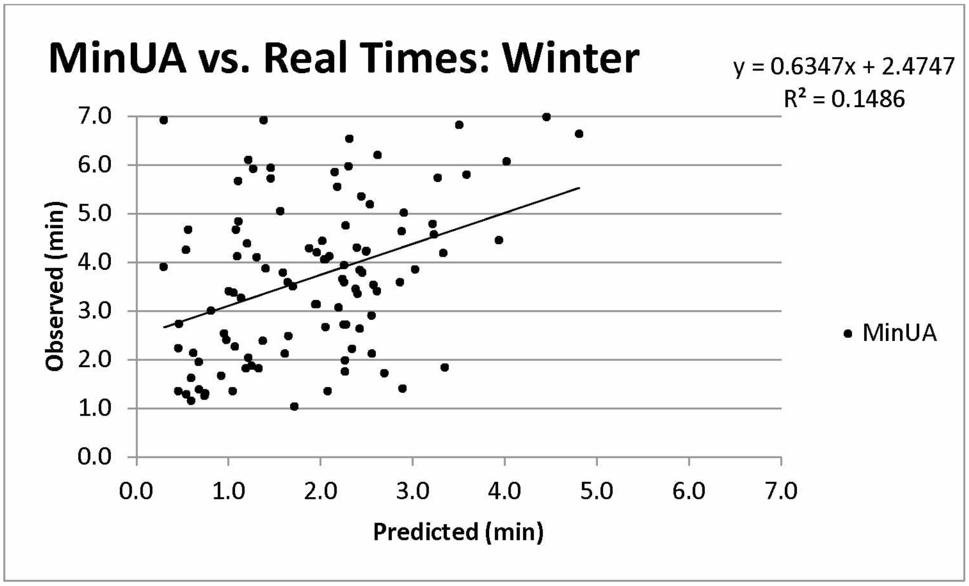

Figure 4.24: The unadjusted network call times vs. observed call times. These calls took place during the winter season.

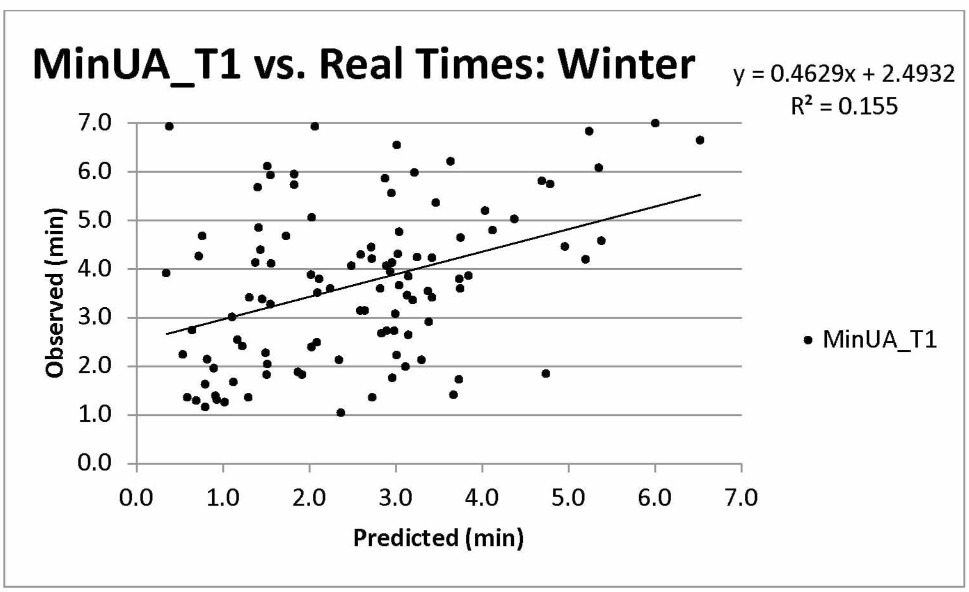

Figure 4.25: Unadjusted, time 1 network call times vs. observed call times. These calls took place during the winter season.

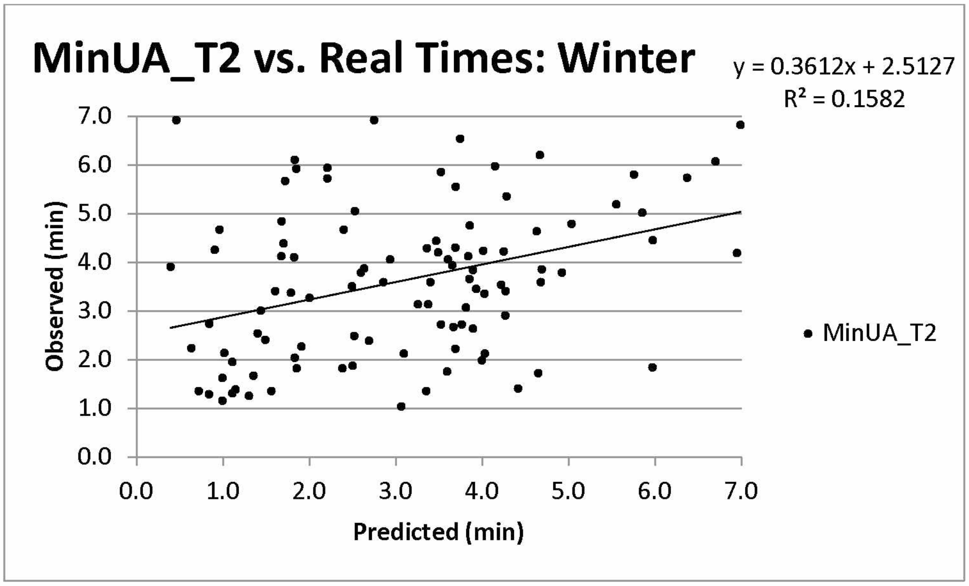

Figure 4.26: Unadjusted, time 2 network call times vs. observed call times. These calls took place during the winter season.

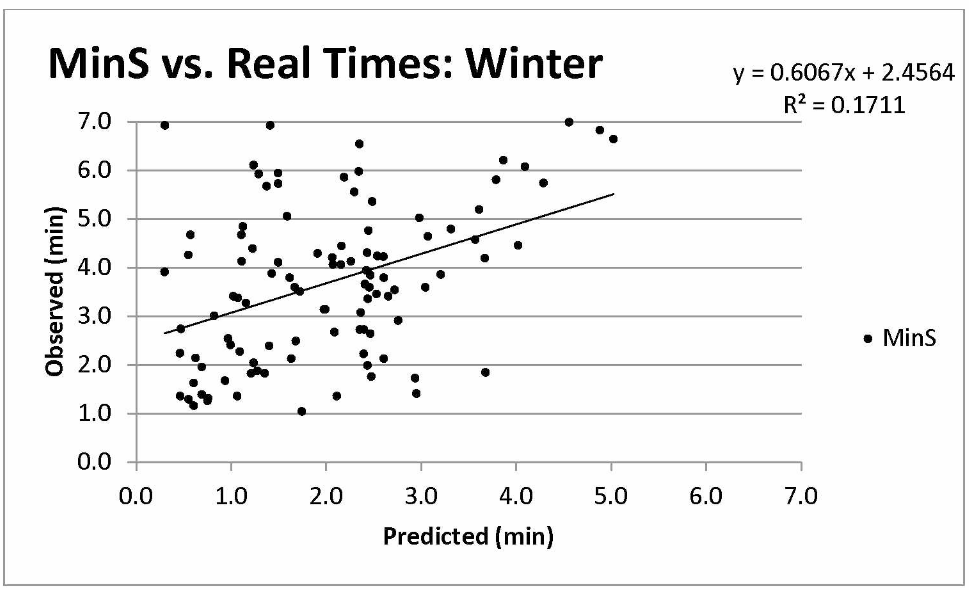

Figure 4.27: Slope adjusted network call times vs. observed call times. These calls took place during the winter season.

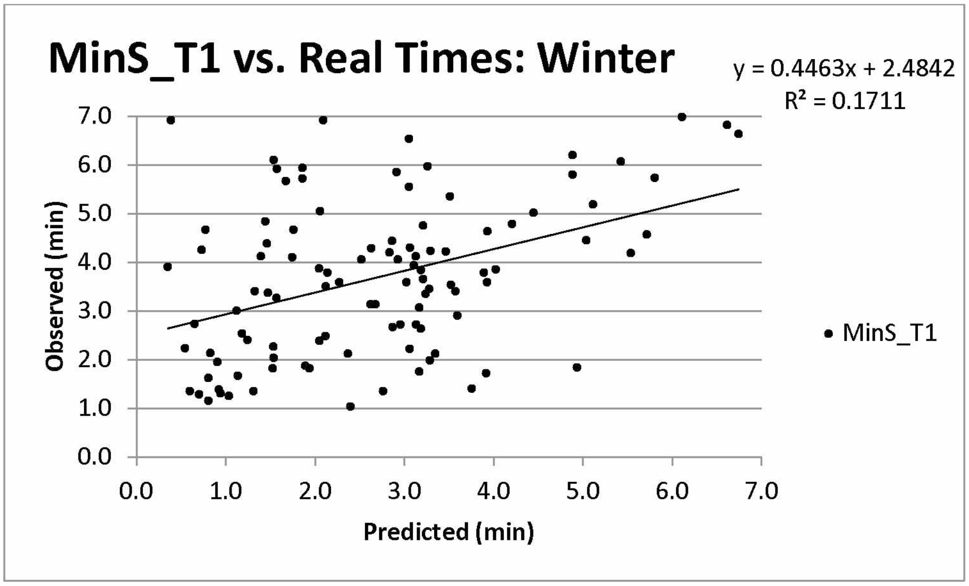

Figure 4.28: Slope adjusted, time 1 network call times vs. observed call times. These calls took place during the winter season.

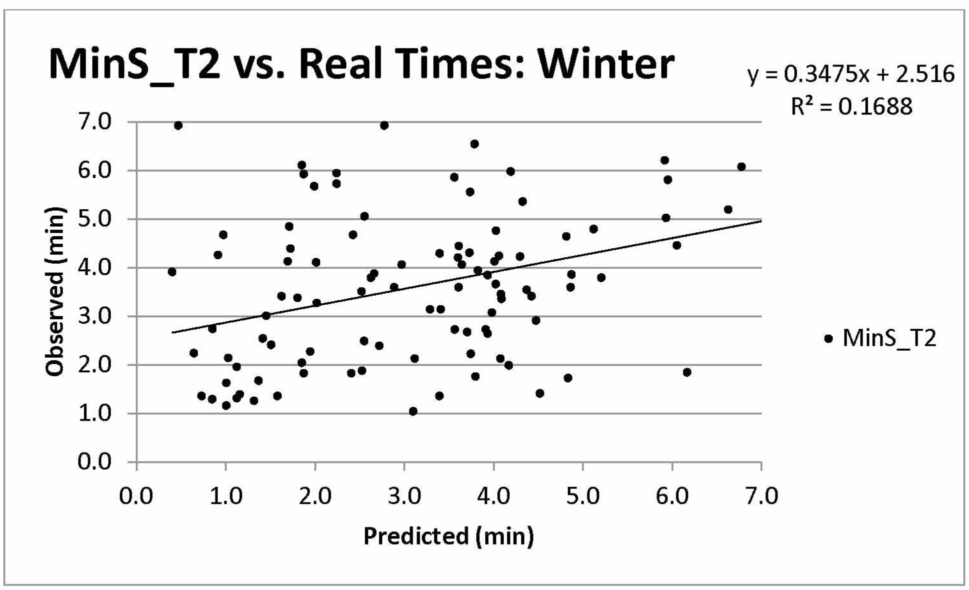

Figure 4.29: Slope adjusted, time 2 network call times vs. observed call times. These calls took place during the winter season.

Table 4.3: Summary of the statistical results of the predicted vs. observed call times. R is the square root of the R^2 coefficient and is a dimensionless parameter. Slope is given in degrees for the linear regression line fitted to the respective scatter plots.

	Total Calls		**Summer Calls**		**Winter Calls**	
	R	**Slope**	**R**	**Slope**	**R**	**Slope**
MinUA	0.403	35.05	0.428	38.99	0.385	32.40
MinUA_T1	0.415	27.10	0.443	30.36	0.394	24.84
MinUA_T2	0.419	21.65	0.446	24.23	0.398	19.86
MinS	0.429	32.56	0.449	34.68	0.414	31.25
MinS_T1	0.433	25.41	0.455	27.44	0.414	24.05
MinS_T2	0.431	20.42	0.454	22.22	0.411	19.16

Table 4.4: Percent of predicted call times within one minute of the observed call times.

	Total Calls (%)	**Summer Calls (%)**	**Winter Calls (%)**
MinUA	33	36	31
MinUA_T1	46	52	46
MinUA_T2	45	50	50
MinS	37	47	34
MinS_T1	48	57	49
MinS_T2	42	43	45

Despite allowing for seasonal variation in call times, the real call times and the predicted times were not well correlated. Possible reasons for this misfit are discussed in detail in section 4.3.1. In general, several major errors were suspected in the collection of call times and in the network itself. To reduce some of these errors and create a robust dataset that could be used to test the network performance, simulated calls were executed in a controlled environment.

4.2.2 Simulated Calls

To validate the observed vs. predicted results, a test area was chosen and as many factors as possible were controlled. The Chena Ridge area in southwest FNSB was chosen as the test area as it included roads that had many turns and highly variable slopes. The Chena Ridge Fire Station, station 42, which serves the Chena Ridge area, was selected as the test facility. The speed limit for all the roads in this area was visually confirmed using the posted speed limit signs and the corresponding speeds in the road network database were updated accordingly. Thirty-one simulated calls were chosen with varying proximity to the station. Nine of these thirty-one calls corresponded to real calls that were part of the original data from dispatch. Each simulated call started at the station and drove the fastest route dictated by the network analysis. All speed limits were observed and the number of different turns per route was recorded. All calls were driven during daylight with no snow or ice on the ground. Figure 4.30 is a map of the Chena Ridge test area showing the locations of the thirty-one destinations selected for the simulated calls. Figures 4.31 through 4.36 are the scatter plots of the simulated call times vs. each predicted network option. Table 4.5 summarizes the statistical results.

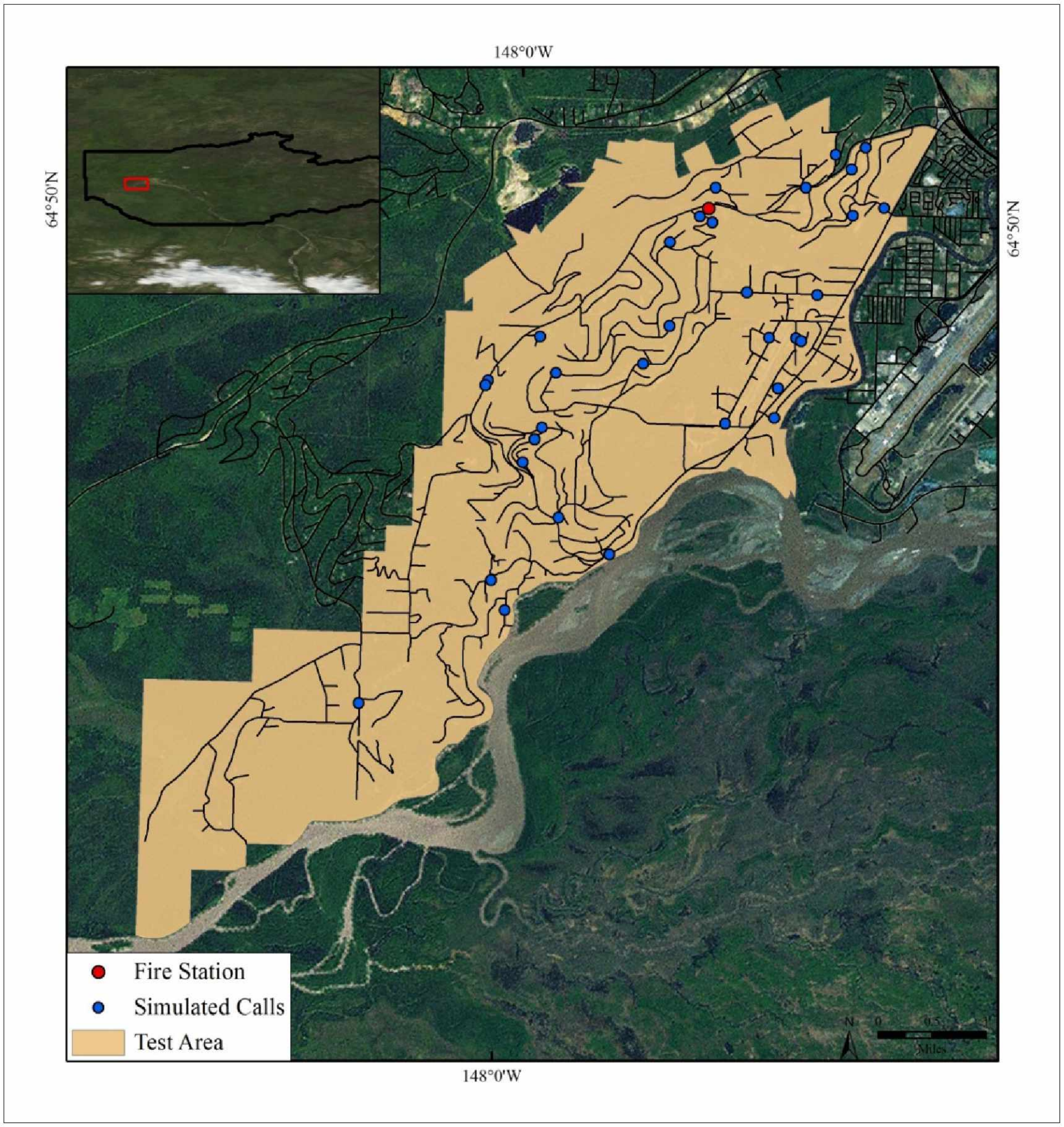

Figure 4.30: Map of the Chena Ridge test area. This map shows the locations of the 31 destinations selected for the simulated calls.

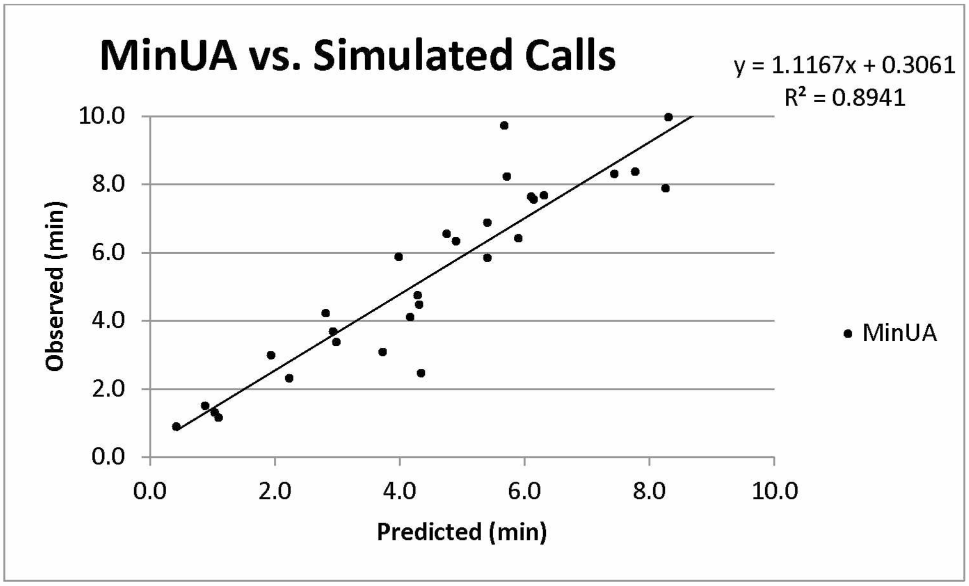

Figure 4.31: Unadjusted network call times vs. simulated call times. The network (predicted) call times are on the x-axis and the simulated (observed) call times are on the y-axis.

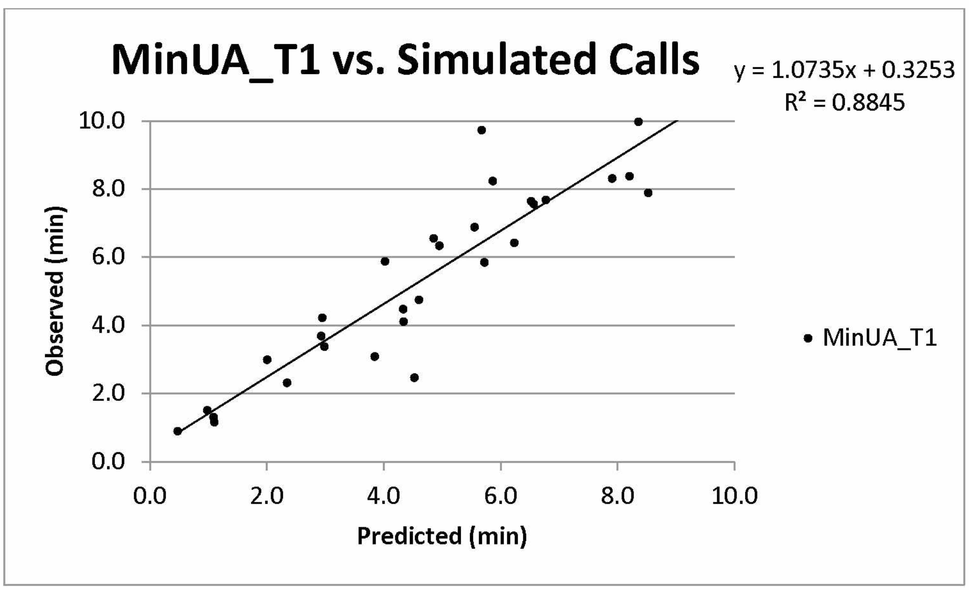

Figure 4.32: Unadjusted, time 1 network call times vs. simulated call times. The network (predicted) call times are on the x-axis and the simulated (observed) call times are on the y-axis.

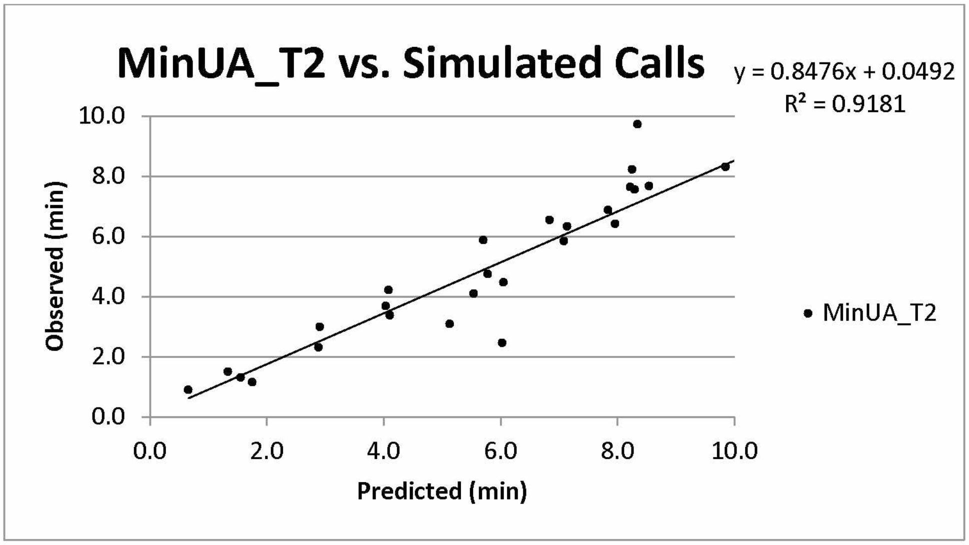

Figure 4.33: Unadjusted, time 2 network call times vs. simulated call times. The network (predicted) call times are on the x-axis and the simulated (observed) call times are on the y-axis.

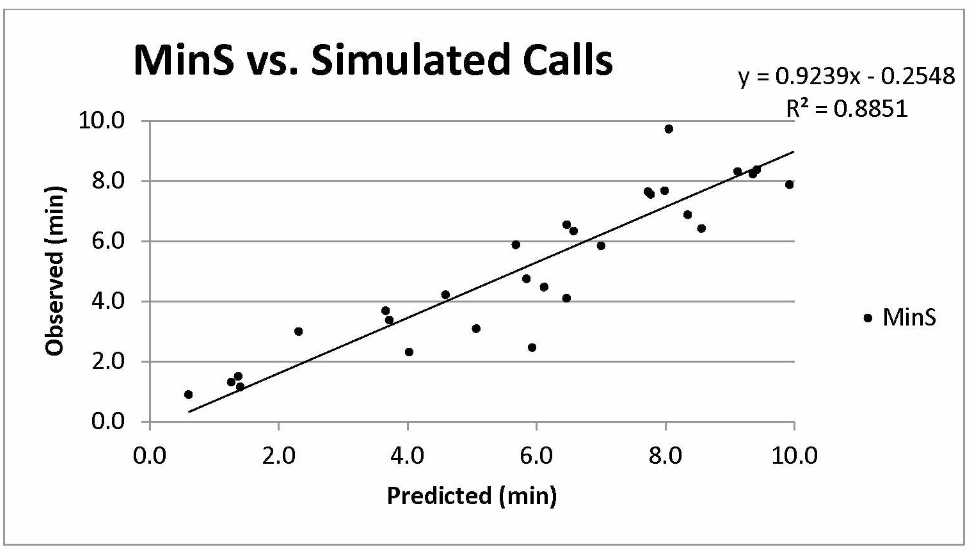

Figure 4.34: Slope adjusted call times vs. simulated call times. The network (predicted) call times are on the x-axis and the simulated (observed) call times are on the y-axis.

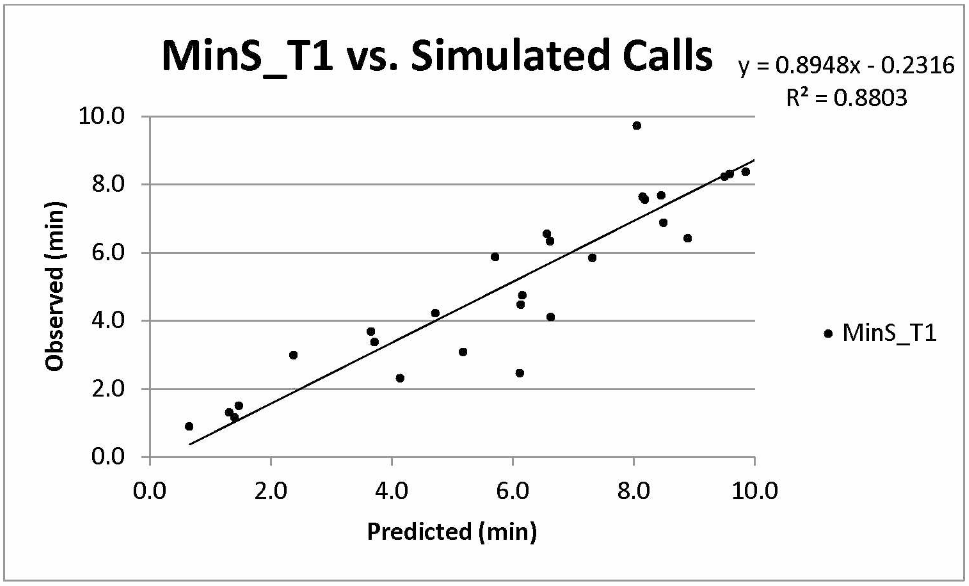

Figure 4.35: Slope adjusted, time 1 network call times vs. simulated call times. The network (predicted) call times are on the x-axis and the simulated (observed) call times are on the y-axis.

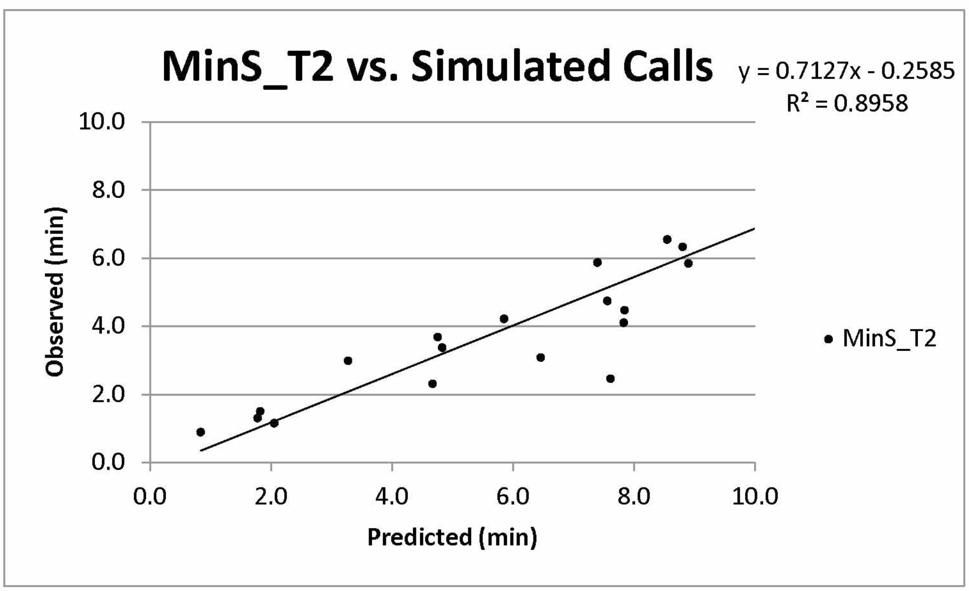

Figure 4.36: Slope adjusted, time 2 network call times vs. simulated call times. The network (predicted) call times are on the x-axis and the simulated (observed) call times are on the y-axis.

Table 4.5: Summary results for the simulated call times vs. predicted network models. R is the square root of the R^2 coefficient and is a dimensionless parameter. Slope is given in degrees for the linear regression line fitted to the respective scatter plots.

	R	**Slope**	**%**
MinUA	0.946	48.16	52
MinUA_T1	0.940	47.03	61
MinUA_T2	0.958	40.28	55
MinS	0.941	42.73	52
MinS_T1	0.938	41.82	48
MinS_T2	0.946	35.48	16

4.3 Network Analysis Discussion

The network performance results using simulated call times were considerably better than the performance results using the real call time data. The comparative analysis helped to identify the limitations in the original call time data. It also helped this study to propose specific recommendations which, if implemented, could make the real call time data more valuable for emergency planning.

4.3.1 Real Call Time Discussion

The initial comparison of 215 actual call times to each of the predicted models had very little correlation (Table 4.3). The R values were all near 0.4, with the highest being the MinS_T1 network with 0.433. The slope of the linear regression line ranged from 20-35°, the highest being the MinUA network with 35.05°. Breaking the calls into summer and winter groups did increase the accuracy of the results, though the correlation still remained low. Most of the R values were close to 0.4 and the slope of the regression line was 22-38°.

Local emergency responders were interviewed in order to gain clarification on the protocols for recording call time data, as well as possible sources of error. Several possible sources were identified in the way the call times are recorded by dispatch and in the network model itself:

1. The information recorded by dispatch does not include where the engine is actually responding from, i.e. the location of the engine when the call was received. An engine could be out on another call, or on driving practice, or other activities outside the station when they are dispatched to an address. Since there is no record of exactly where the engine starts, when running the network it was assumed to start from a station and end at a the destination address of the call. This discrepancy is a major source of error causing low performance indicators in the network analysis results.

2. Another source of error is one that became evident when plotting the call times. An engine is not always responding to an actual address point, as it could be responding to a car crash somewhere along a road or an intersection. This can also introduce variability in the call times.

3. A third source of error when recording call time is human error. There can be a time lag between the time a responder radios that they are en-route, and the time that they actually are. The same can happen when arriving on the scene. During a long call, this approximately 30-60 second lag time has little effect, but on the shorter 1-3 minute calls possible lag times can have a much greater effect.

4. There were also some errors identified in the network itself. The network base is the road shapefile with speed limits. The original Borough and FMATS databases are not entirely accurate. In some areas the speed limits are incorrectly identified and this can have a direct impact on the accuracy of the network itself.

5. The identification of one-way roads and road type can also improve the network accuracy. The known one-way roads were accounted for when building the network, but there may be others that need to be identified.

The recognition of these possible sources of error during the analysis is what led to identifying a test area and running a set of simulated calls.

4.3.2 Simulated Call Time Discussion

After identifying sources of possible error a test area and set of simulated calls was established. Running controlled simulated runs and verifying the basic road network greatly increased the accuracy of the analysis results. As mentioned previously, nine of the thirty-one simulated calls corresponded to actual calls that were in the original data set. Of these nine calls, six of the simulated times where within one minute of the actual call time and the remaining three simulated times were within two minutes of the actual call time. While there were only nine calls that could be compared, the simulated calls provided a way to gather controlled data that would be relatively close to an actual emergency response call time.

The results of the simulated call times compared to each of the predicted network options were very positive (Table 4.5). All the R values were greater than 0.90, with the highest being the MinUA_T2 network with an R value of 0.958. The slope of the linear regression lines were 35° - 48°, with the closest to a 45° line being the MinUA_T1 network. MinUA_T1 also had the highest percentage of calls, 61%, within one minute of the simulated call time. MinUA_T1 was chosen as the best fit network because of the slope of the regression line and the amount of predicted call times within 1 minute of the simulated call times, while still maintaining a high R value of 0.94.

4.4 Limitations

The results of comparing different network options to real call times highlighted some important limitations of this study. Due to the various errors mentioned in section 4.3, it was not possible to identify which network option is the most accurate for Borough-wide conditions. It is clear that a network analysis is capable of identifying general service areas based on time or distance from a station. While it was possible to use the available real call time data to test different networks, the accuracies of those test results were low. The simulated calls provided a controlled environment, and data from these calls could be successfully used to test the effects of the different time penalties on the network performance. It should be noted that the service area produced for the Chena Ridge area is only statistically accurate for that area. As previously mentioned, the Chena Ridge area is a variable-slope area with many curves. There are other areas in the Borough that are mostly straight highway areas or areas that are in a downtown configuration with stop and go traffic. While it is entirely possible that the MinUA_T1 network configuration could be accurate for other areas in the Borough, or the entire Borough, more simulated calls would be needed in all major areas within FNSB in order to determine whether this assumption is valid.

Chapter 5: Evacuation Zones

This chapter discusses the creation of evacuation zones for FNSB and the inclusion of these zones in a map book that can be used for emergency planning and response purposes. In Chapter 1 the 2011 Moose Mountain fire was introduced. This fire highlighted the need for a resource that would provide quick access to houses, people, and critical infrastructure in any area within the Borough. Evacuation maps were created for the entire Borough. The accuracy of information on these maps is dependent upon the accuracy of the input data, particularly the Borough road data, the slope data, and the census data. The map book generated from this research can be used in general evacuation planning and also for emergency evacuation planning purposes, for instance combating a wildfire that suddenly starts or moves into an inhabited area.

5.1 Creating the Zones

While the total area within the Borough is 7443 sq. mi., the area where people are living is considerably smaller and follows the road network. People are still spread out compared to most areas in the U.S. and there can be many challenges when trying to respond to a disaster or evacuate an area. Therefore, inhabited areas of the Borough were broken into zones.

To define the zones the Borough road shapefile and address point shapefile were overlaid on satellite imagery. The zone boundaries were then drawn taking into account two key considerations. The first consideration was access to a major road. Most of the address points fall in clusters, connected by a road system. Most neighborhoods follow a typical pattern of houses connected by local roads that have at least one exit point onto a major road. When drawing the zones it was necessary to make sure that as many exit points from a neighborhood were included in a zone as possible. The next consideration was accounting for physical barriers and general terrain. For example, a fire or flood is less likely to travel over a large hill or ridge than down a valley or a flat, densely wooded plane. Therefore, in most cases it did not make sense to draw a zone that had a ridge going through the middle of it. There were a few neighborhoods, e.g. Murphy Dome, that are built on a ridge, but this area was broken into several zones instead of one big zone (Figure 5.1). This same principle applied to an area with a river, large lake, or other natural or man-made break in the landscape (Figure 5.2).

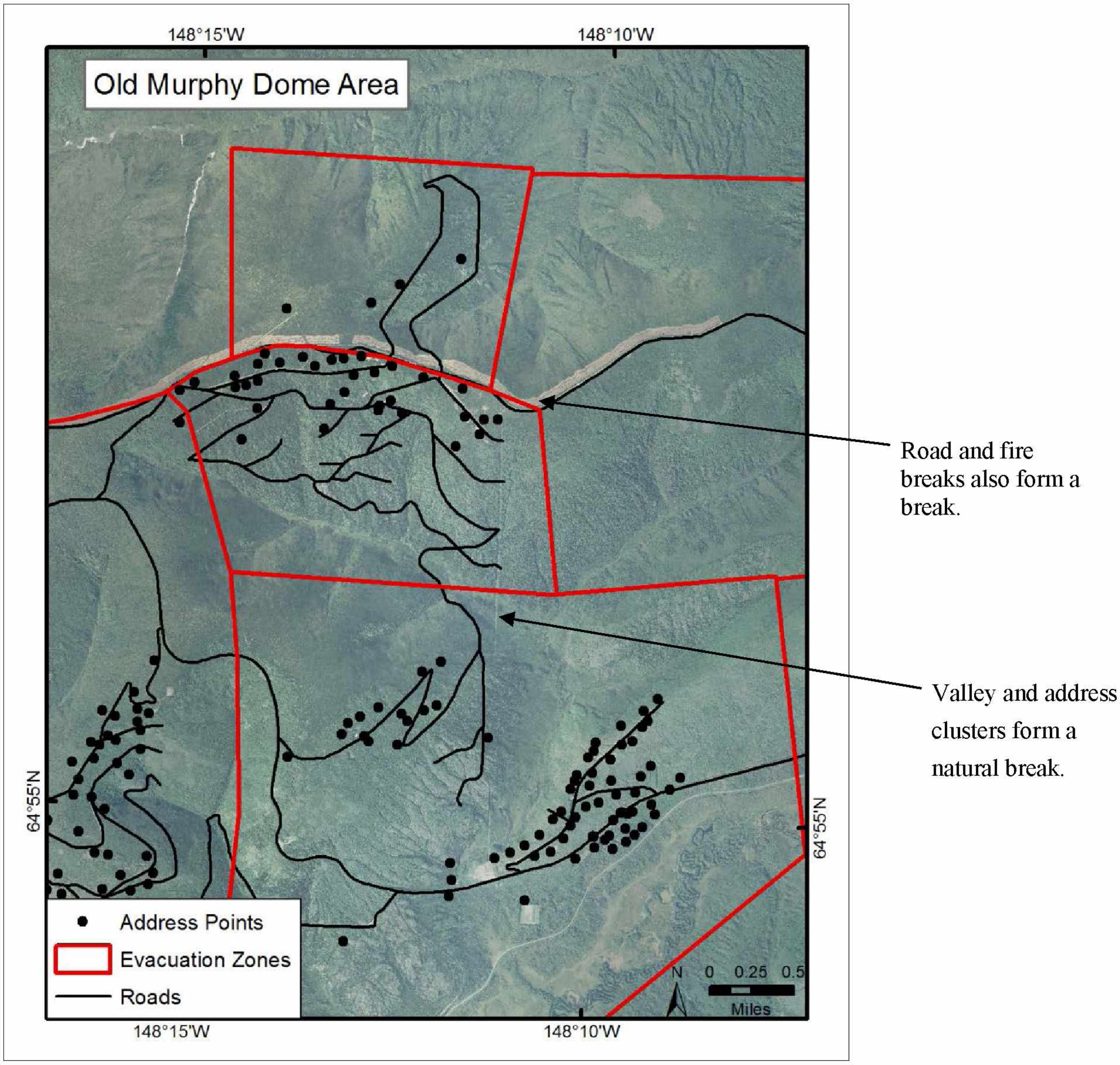

Figure 5.1: Example of several evacuation zones. The houses naturally cluster into neighborhoods connected by local roads. The satellite imagery reveals location of ridges and valleys, as well as a man-made fire break put in by the Alaska Fire Service (light brown rectangular areas following the road in the northern part of the figure). Zones that share a common road can be seen, but the neighborhood is never cut off from access to a major road.

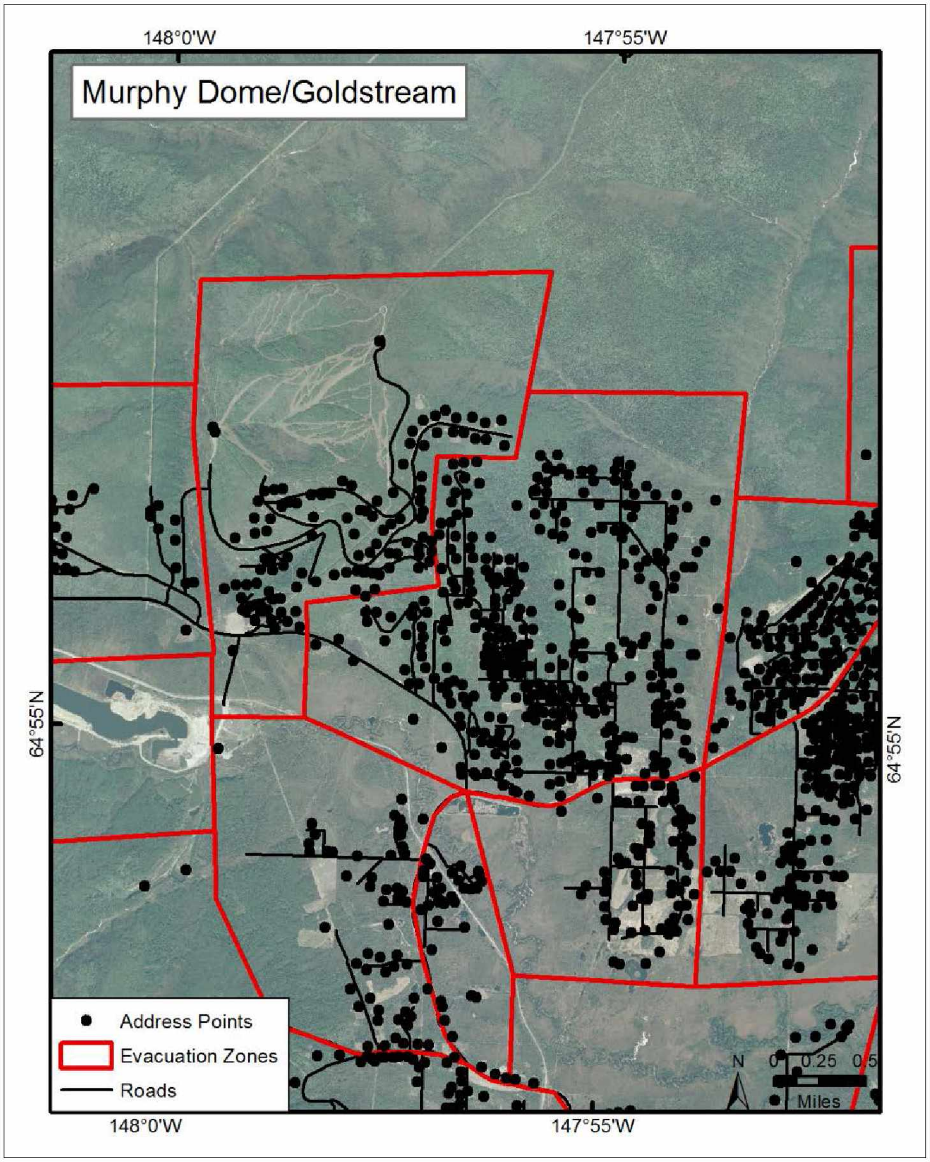

Figure 5.2: A second example of drawing evacuation zones. A major road is used as a natural break and general topography and clustering of houses is observed.

There were a total of 152 zones created and they encompassed all occupied address points along or near the road system, with a combined area of 1042 sq. mi (Figure 5.3). The next step was to assign each address point to a zone. For this, *Spatial Join* was used with the address point shapefile (section 3.3) as the Target and the new evacuation zone layer as the Join. The Join Operation was 'One to One' and the Match

Option ‘Within’; “Keep All Target Features” was selected. This operation created a new address point file that now had a field with the zone name in which the address point resided. The *Frequency* tool was then executed with the following conditions:

Input Table: The newly joined address/zone point shapefile

Output Table: Name of table that will be saved

Frequency Fields: The “ZoneName” field was selected. This will calculate the number of times a particular zone was listed, thereby giving the total number of addresses in each zone.

Summary Field: The Avg_Population field was selected; this will calculate the total number of people per evacuation zone.

The result of this tool was an output table that had the evacuation zone name, how many address points were in each zone (frequency field), and the total population for each zone based upon the summation of average people/house of all the address points in a zone. The *Join Field* tool was then used to join this output table to the Evacuation Zone shapefile based on the zone name field. This resulted in a polygon shapefile with the attribute table featured in Table 5.1. Figure 5.3 is a map of all the evacuation zones color coded by population density.

Table 5.1: Attribute table for the Evacuation Zone shapefile. This is what the table looks like after joining with the address population shapefile. NAME is the name of the evacuation zone, STRUCTS is the number of structures (probable address points), TOTALPOP is the total population of the zone, AREA is the area in sq. mi., POPDEN is the total population divided by the area, and STRUCTDEN is the number of structures divided by the area.

NAME	STRUCTS	TOTALPOP	AREA	POPDEN	STUCTDEN
Hattie/Resolution	26	52	1.93	26.91	13.46
Darling/McCall	35	35	6.23	5.62	5.62
Desperation	4	3	2.05	1.47	1.95
Cascade/Grand Teton	34	66	2.65	24.89	12.82
Old Murphy/Spinach Creek	6	15	10.42	1.44	0.58
Abraham	66	133	15.67	8.49	4.21
Yellow Knife/Murphy Dome	76	164	10.16	16.15	7.48

The zones of concern that were received from the Forestry Service show zones in the Borough that could potentially be at higher risk for wildfires. These areas were combined with the evacuation zones using a *Spatial Join* in order to highlight the evacuation areas associated with high risk areas for wildfires (Figure 5.4).

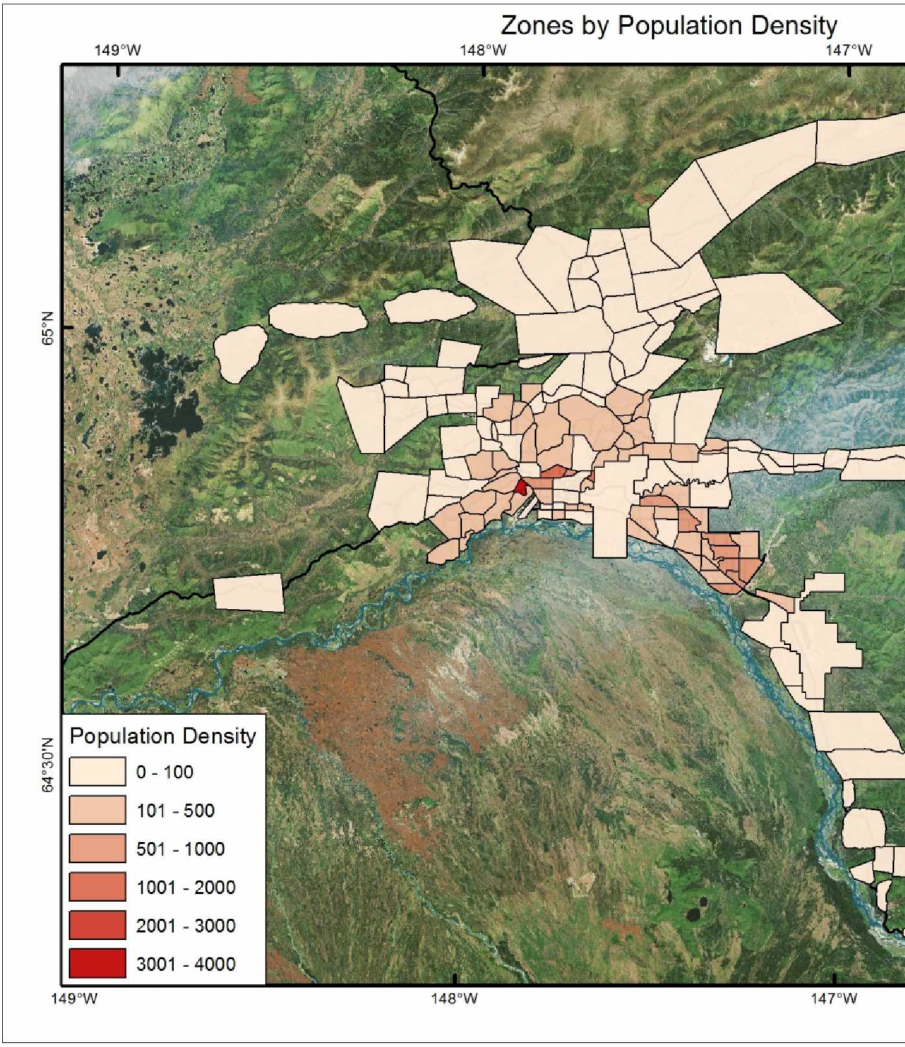

Figure 5.3: Evacuation Zone map categorized by population density.


65°N
64°30'N
146°W
146°W
0 2.5 5 10
Miles
N

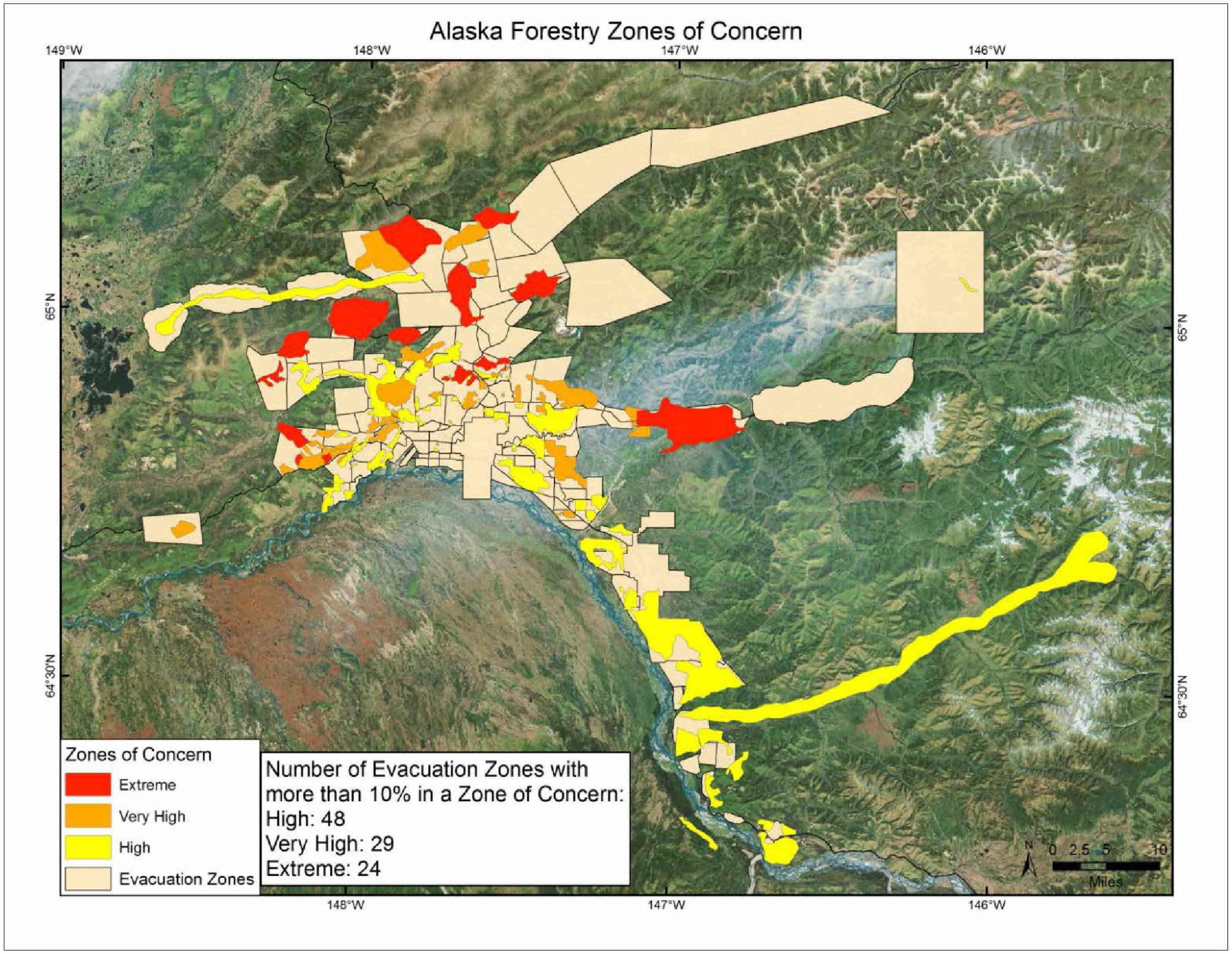

Figure 5.4: Forestry zones of concern overlaid on the evacuation zones. The inset box to the right of the legend gives the number of evacuation zones that have more than 10% of their area in a zone of concern.

5.2 Map Book

Map books have been used in emergency response for years as a way to divide a large area into detailed maps for use by emergency vehicle drivers. This original use of the map book was combined with the evacuation zones to create a new kind of map book, one geared specifically towards evacuation planning and disaster response. In this map book each zone has a designated page that includes the critical information and key resources for that particular area. This is a resource that can be printed out in hard copy or used as a GeoPDF. A GeoPDF works like any other Portable Document Format (PDF), but it also has the spatial coordinates embedded in the document. If opened on a GPS enabled device, then one could locate themselves within the map book and immediately see details about their surrounding area.

The map book was created in ArcMap using *Data Driven Pages* with the evacuation zone polygon shapefile as the data layer. Each zone is the center map of its own page. Under the center map on the left is general information about the zone including total population, population per house, total number of possible houses, center coordinate for the zone, and the total area. Underneath this information is a legend that displays any resources in the zone that either could be used to fight a disaster or structures that might increase the disaster, for example an oil refinery. The complete list of resources mapped for each zone is as follows: fire station, police station, schools, hospitals, airfield, oil refinery, communication towers, known hazardous material sites, houses/structures, pipeline, and railroads. To the right of this information is an inset map that displays the surrounding zones. There are two versions of the map book, one in color and one in black and white. The color version has the Pictometry imagery as the map background. The black and white version has the ESRI light grey map layer as the background. Figure 5.5 is an example of a color version map page and Figure 5.6 is an example of a black and white version map page.

To use the map book, a township and range set of look-up maps was created and included in the beginning of the book as index maps. Figure 5.7 is an example of a township and range look-up page. Zone pages were then ordered alphabetically. A street index was established in the back of the book that enables users to look up a zone using a street name and address number. Figure 5.8 is an example of one of the street index pages. The map book also includes some general reference maps that have the zones classified by population density (Figure 5.3) and structure density, followed by the classified map from the Department of Forestry showing general areas of concern (Figure 5.4). Appendix C (found on the CD in pocket) is the complete color version of the map book.

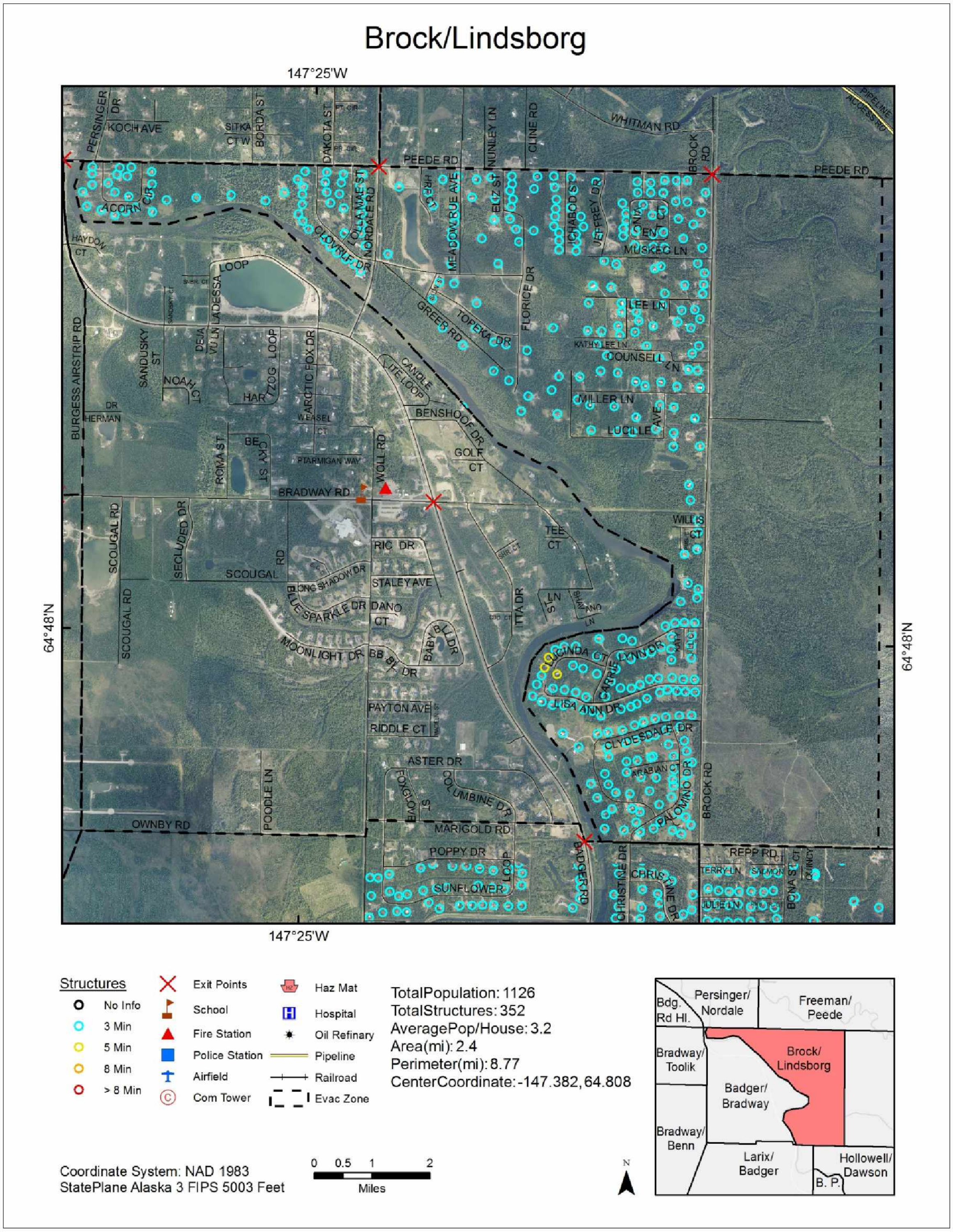

Figure 5.5: Color map book; example of an evacuation zone page.

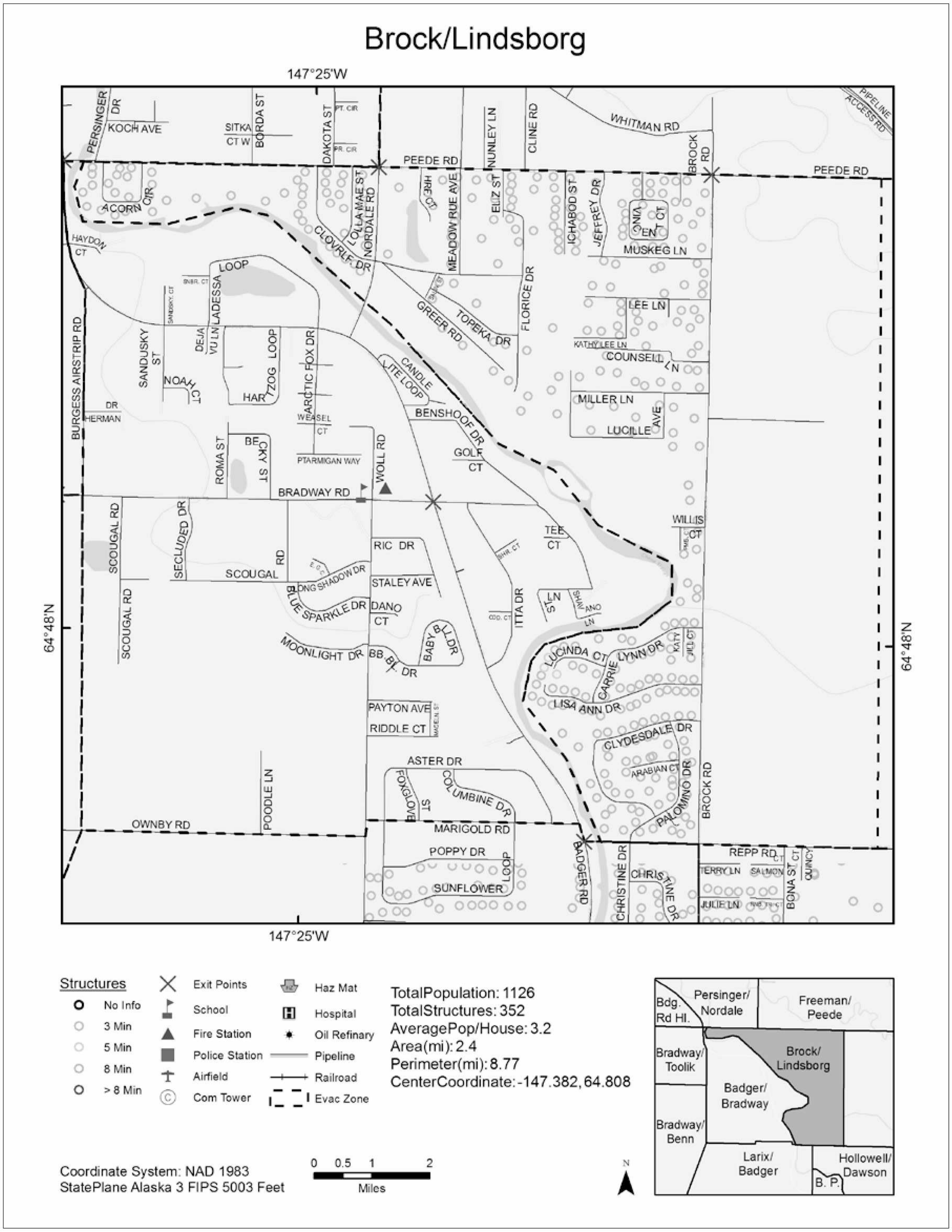

Figure 5.6: Black and white map book; example of an evacuation zone page.

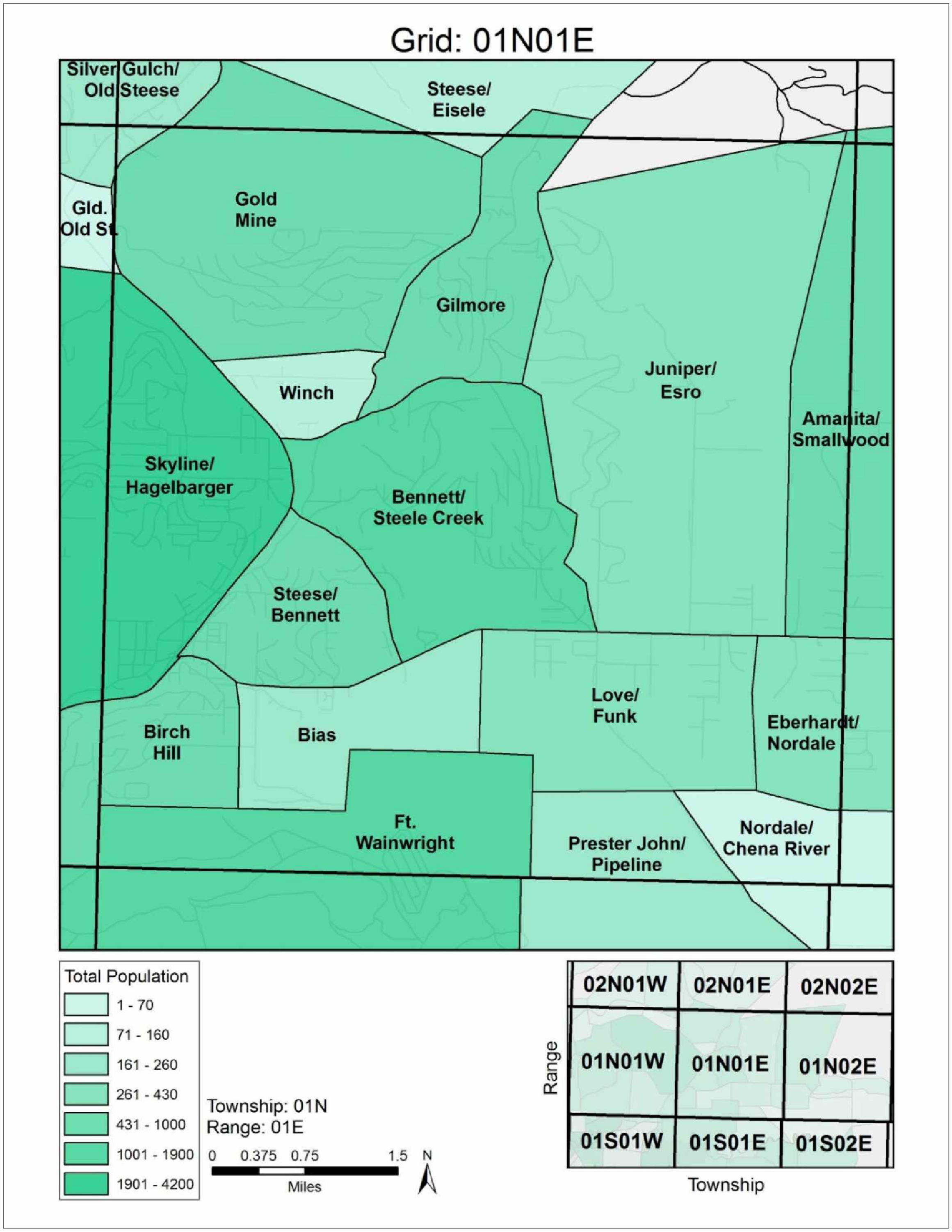

Figure 5.7: Example of a township and range look-up page within the map book.

Street	City	Left:From	Left:To	Right:From	Right:To	Evacuation Zone
33' RD	FAIR	481	201	480	200	Auburn/Grenac
A ST	FAIR	142	194	143	195	Trainor Gate South
A ST	FAIR	196	210	197	209	Trainor Gate South
A ST	FAIR	212	336	211	339	Trainor Gate South
A ST	FAIR	338	362	341	365	Trainor Gate South
A ST	FAIR	400	422	399	421	Trainor Gate South
A ST	FAIR	424	474	423	473	Trainor Gate South
A ST	FAIR	476	514	475	513	Trainor Gate South
A ST	FAIR	516	648	515	649	Trainor Gate South
A ST	FAIR	650	798	651	799	Trainor Gate South
ABERDEEN RD	FAIR	1066	1088	1067	1089	Badger Rd/Holmes
ABRAHAM RD	FAIR	5601	5925	5602	5924	Abraham
ABRAHAM RD	FAIR	5927	6121	5926	6120	Abraham
ABRAHAM RD	FAIR	6145	6479	6146	6480	Abraham
ABRAM DR	FAIR	1864	1878	1865	1879	Larix/Badger
ACE RD	FAIR	3159	3201	3160	3200	Henderson/GoldHill
ACORN CIR	FAIR	1060	1174	1061	1173	Brock/Lindsborg
ACRE ST	FAIR	326	398	327	399	Birch Hill
ADA ST	FAIR	1601	1699	1600	1698	Airport/Mitchell
ADA ST	FAIR	1701	1799	1700	1798	Airport/Mitchell
ADA ST	FAIR	1801	1899	1800	1898	Airport/Mitchell
ADA ST	FAIR	1901	1999	1900	1998	Airport/Mitchell
ADA ST	FAIR	2001	2199	2000	2198	Airport/Mitchell
ADAK AVE	FAIR	2	22	1	23	Trainor Gate South
ADAK AVE	FAIR	24	64	75	127	Trainor Gate South
ADAK AVE	FAIR	100	140	129	145	Trainor Gate South
ADAMS DR	FAIR	3213	3217	3266	3270	Airport/Mitchell
ADAMS DR	FAIR	3281	3295	3280	3292	Airport/Mitchell
ADELAIDE CT	FAIR	3160	3210	3161	3211	Tribly/Schloesser
ADIT LN	FAIR	2021	2095	2022	2096	Hattie/Resolution
ADONIS AVE	FAIR	4904	4926	4905	4927	Baker/Hope
ADONIS AVE	FAIR	4928	4992	4929	4991	Baker/Hope
ADRIANA WAY	NORT	2406	2438	2407	2439	Old Rich/Santa Claus
ADRIANA WAY	NORT	2440	2468	2441	2469	Old Rich/Santa Claus
ADVENTURE RD	FAIR	641	731	640	740	Foxboro/Adventure
ADVENTURE RD	FAIR	785	849	786	850	Foxboro/Adventure
AEROFUEL PL	FAIR	5851	5863	5850	5864	Airport West
AEROFUEL PL	FAIR	5865	5999	5866	6000	Airport West
AERONCA AVE	FAIR	5091	5195	5090	5194	Airport West
AERONCA AVE	FAIR	5197	5305	5196	5306	Airport West
AGATE AVE	FAIR	2869	2891	2870	2892	Coyote/Jones
AGGRAVATION ALY	FAIR	280	300	281	301	Birch Hill
AGNES LN	FAIR	894	974	895	975	Freeman/Peede
AICUZ AVE	FAIR	5670	6020	5671	6021	Richardson/Grieme
AILERON CT	FAIR	3330	3354	3331	3353	Flight/Redstone
AIRLINE DR	FAIR	1098	1140	1097	1141	Badger Rd/Holmes
AIRLINE DR	FAIR	1142	1162	1143	1161	Badger Rd/Holmes
AIRLINE DR	FAIR	1164	1182	1163	1181	Badger Rd/Holmes
AIRLINE DR	FAIR	1184	1226	1183	1227	Badger Rd/Holmes
AIRLINE DR	FAIR	1228	1260	1229	1259	Badger Rd/Holmes
AIRLINE DR	FAIR	1262	1356	1261	1355	Badger Rd/Holmes
AIRLINE DR	FAIR	1358	1382	1357	1381	Badger Rd/Holmes
AIRPORT INDUSTRIAL RD	FAIR	5015	5039	5010	5032	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5041	5051	5034	5046	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5053	5077	5136	5160	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5161	5177	5162	5176	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5179	5195	5180	5248	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5349	5415	5310	5456	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5501	5561	5458	5590	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5601	5611	5600	5610	Airport West
AIRPORT INDUSTRIAL RD	FAIR	5799	5891	5736	5880	Airport West

Figure 5.8: Example of a street index page in the map book.

5.3 Evacuation Routing

Once the map book and the network analysis were complete, the two products were combined. One to three ‘exit points’ were chosen along major roads and designed to create a flow of people directed on a route that would allow them to continue their evacuation. For instance, if there was a zone where the east end led into a dead end a few miles down the road and the west end was the way out of that general area, the exit point would be placed on a major road on the west end. The address and exit points were then loaded into the network as incidents and facilities, respectively. Using the best fit network option, MinUA_T1, the fastest route time was calculated from each address to the nearest exit point. The addresses were then color coded based on the drive time. This kind of information can now give a manager or responder an estimate of how long it would take people to drive out of a dangerous area and into a safe area. Identifying which houses would take the longest and which ones the shortest time to evacuate enables a manager to make more effective decisions regarding issuing evacuation orders and controlling traffic. Figure 5.9 is an example of a map book page with the color coded address points.

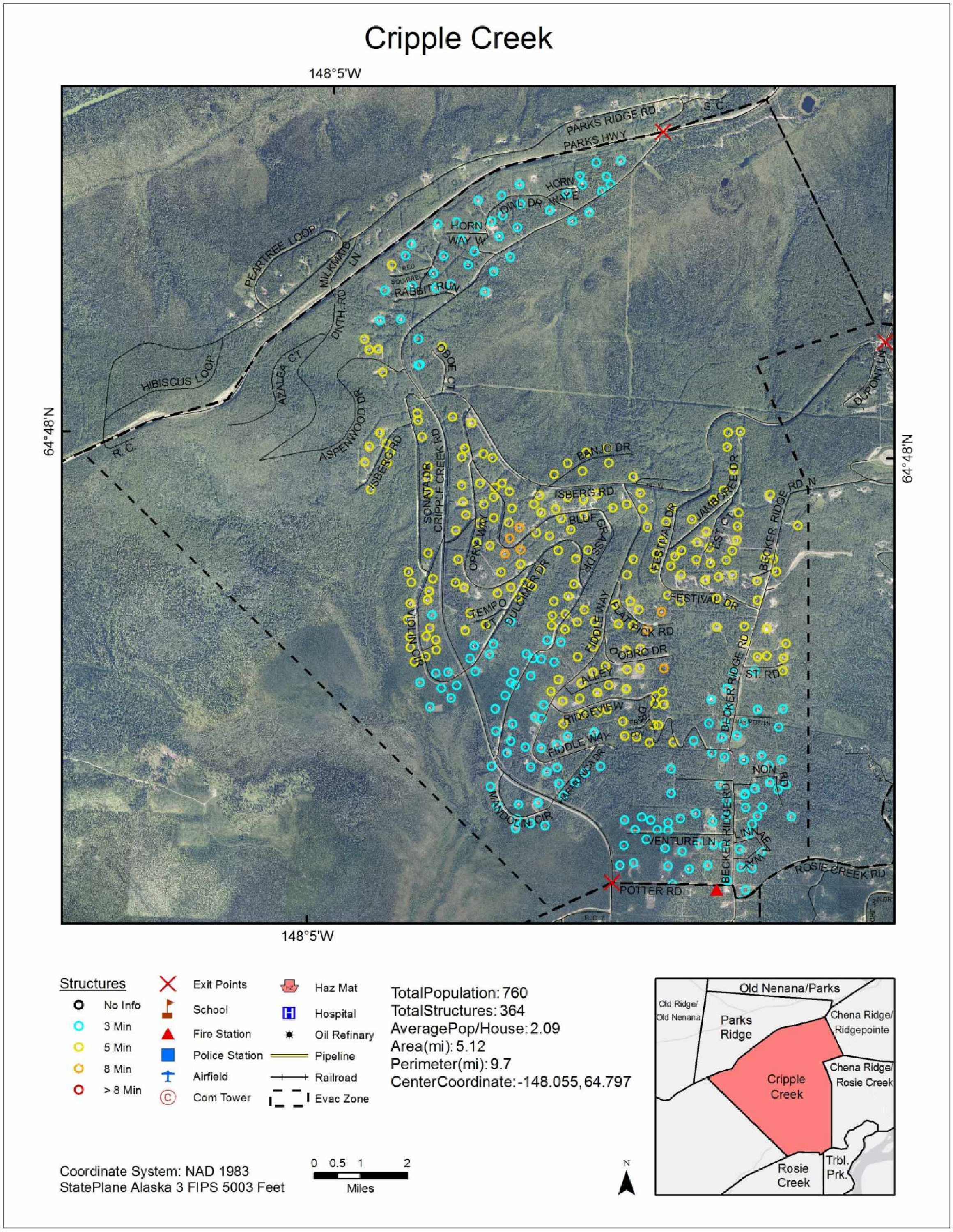

Figure 5.9: Example of a color map book page with coded structures.

5.4 Discussion

Current GIS tools enable the creation and tailoring of the common map book product for emergency response and evacuation purposes. The evacuation zones and exit points were manually created, which allowed for greater customization and flexibility. All of the critical infrastructure datasets were already available and this allowed for quick and easy inclusion in the map book. The combining of known address points with the 2010 Census dataset was effective and created a way to harness that information without infringing on people's privacy. During an emergency or evacuation scenario, being able to quickly estimate how many people are in an area, and where in that area they may reside, can save time and enable more effective planning and evacuation.

The map book is a product that first responders are already familiar with using. Generating map book pages as GeoPDF's has additional advantages. GeoPDF's can be quickly disseminated digitally and can be easily loaded on GPS units or other geospatially enabled devices. Combining the network analysis with the map book allows managers to realize the time that would be required for a quick evacuation. While it does not model how long it would take people to get ready to evacuate, it does provide managers with a sense of how long it would take them to leave, highlighting areas within a zone that might take longer to evacuate. There are some areas in the Borough where this may be obvious from visual analysis or personal experience. In other areas it may be more difficult to visually identify address clusters that might take longer to evacuate than others. Combining the analysis with the map book produces a unique tool, customized for the local area, that can enhance evacuation planning and emergency response.

5.5 Limitations

It is important to note that this map book, the evacuation times, and the population and structure data are meant to be used as general guidelines. Disasters on any scale can be unpredictable and the situation can change very quickly. This product provides a general overview of an area based on the data that is currently available. Each dataset inherently contains some error and that error propagates to the map book pages. The addition of structures or roads can affect the relevancy of certain maps. The way the census population was combined with the address dataset is an average taken over a certain area. It is meant to give a general estimate, not provide a detailed account of a neighborhood. Used appropriately, this map book can provide quick and useful information, but it does not replace critical thinking or on-hand situational awareness.

Chapter 6: Conclusions and Recommendations

This thesis created several decision support tools for use by emergency responders and managers in FNSB. A network analysis was created using data provided by local agencies. This analysis produced service area maps for each fire station, allowing emergency responders to assess their response times and allocation of resources. The Borough was divided into evacuation zones and a map book of these zones was created, listing critical infrastructure and key resources. The network analysis and map book were then combined, producing a map book that has addresses color coded by the time it would take to evacuate an area. Methods for generating these products were also designed and documented with the goal that they can be applied to other similar communities, and the products themselves could be continuously updated.

6.1 Network Analysis Conclusions

The network analysis tested the addition of time penalties to improve the accuracy of modeling emergency response travel times. The two different penalties tested were the slope of a road (does a high slope slow down a fire apparatus), and delays due to the number and type of turns during a route. These two variables were combined in several different ways, giving a total of six different network options that were tested against real emergency response call times and simulated call times.

It was found that in order to test the performance of different network options and determine which network was optimal for predicting travel times, it was necessary to have an accurate and verified call time dataset. Additionally, it was important that the networks were themselves based on input datasets (roads, slopes, etc.) that were accurate. Inaccuracies in the recorded speed limits of roads produced a certain amount of error in portions of the network. There were also several problems in using real call time data to test each network option. First, there is no record of the origin of an engine or the final destination. It could only be assumed that an engine originated from a fire station and arrived at the direct address given. The inability to separate those calls from ones with unknown origin or destination made testing the different network options difficult and resulted in poor correlations.

To evaluate each network option, a test area was selected and controlled, simulated call times were generated. This proved effective in simulating real call times and allowed the evaluation of each network option. For the test area, the MinUA_T1 network was chosen as the best fit. MinUA_T1 was the network that did not account for slope, but added a time penalty for right turns (2 sec), left turns (5 sec), U-turns (15 sec), and going straight through an intersection (1 sec). Having an accurate network analysis allows for the creation of service area maps for each fire station. Maps were created for each station in 3, 5, and 8 minute areas, as well as a 1.5 mile area. These maps allow emergency responders to utilize their time and resources to the fullest extent. The use of local data to produce a network analysis was found to be useful in generating service areas customized for FNSB. While several problems were discovered when using local data and evaluating the networks, it is recommended that the analysis be updated as better data becomes available.

6.2 Evacuation Map Book Conclusions

Dividing the Borough into evacuation zones and creating a map book of these zones proved to be a useful time saving element during a disaster response, as proved by the 2011 Moose Mountain fire. The inclusion of population information, critical infrastructure, and key resources creates a valuable and effective resource that can be used in the planning stages, as well as in the response and recovery stages of any disaster type or scale. Combining the network with the map book enhances the product by identifying which areas have the longer evacuation routes. This allows managers to make more effective decisions and increases routing efficiency.

An evacuation map book is an effective tool that can be easily updated and disseminated to a diverse group of emergency responders and decision makers. It can be tailored to any community and is capable of enhancing local evacuation and response efforts.

6.3 Recommendations

Recommendations for future work include selecting more test areas within the Borough that include varying turns and slopes, in order to evaluate each network option for different regions (flat, hilly, few turns, etc.). This would improve the validity of the network and could potentially make it necessary to choose a different network option for different areas. Updating and verifying the basic road information including speed limits and one-way status is required to enhance the accuracy of the network model. Three other recommendations to consider are as follows:

1. Include a surface attribute for each road (paved, gravel, dirt, etc.).
2. Note when a road type changes at an intersection, for instance turning from a major road onto an artillery road.
3. Take into account traffic congestion, rush hour, or unforeseen blocks in the system.

While the map book can currently be used in print form, as well as on mobile devices in GeoPDF form, it could also be very effective as a smart phone application. Many responders already have and use smart phone applications in their daily lives and the creation of an "app" could enhance the integration of the map book into current emergency response workflows.

As previously mentioned, the continual inclusion of better data will enhance accuracy. New information and datasets are released on a regular basis and it is important to keep these products updated. Allocating resources to increase the quality of base data would also be a benefit. Input data needs to undergo a quality assurance and quality check (QA/QC) by trained personnel. Multi-agency coordination should continue to improve data sharing and quality enhancement. This ensures delivery of a timely, accurate, and ready to use product. It is also important to create public awareness about these products and encourage their use by emergency responders on a regular basis. This will ensure that emergency responders and the general public are familiar and at-ease with using the products during emergency situations.

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Appendix A: Service Area Maps

Appendix A includes fire service area maps for the entire Borough (Figure A.1), as well as individual service area maps for each of the eight different fire service areas: Chena-Goldstream (Figure A.2), Ester (Figure A.3), Fairbanks City (Figure A.4), North Pole (Figure A.5), North Star (Figure A.6), Salcha Rescue (Figure A.7), Steese (Figure A.8), and University (Figure A.9). Each service area map was created using the MinUA_T1 network option and divided into 3 min, 5 min, and 8 min areas.

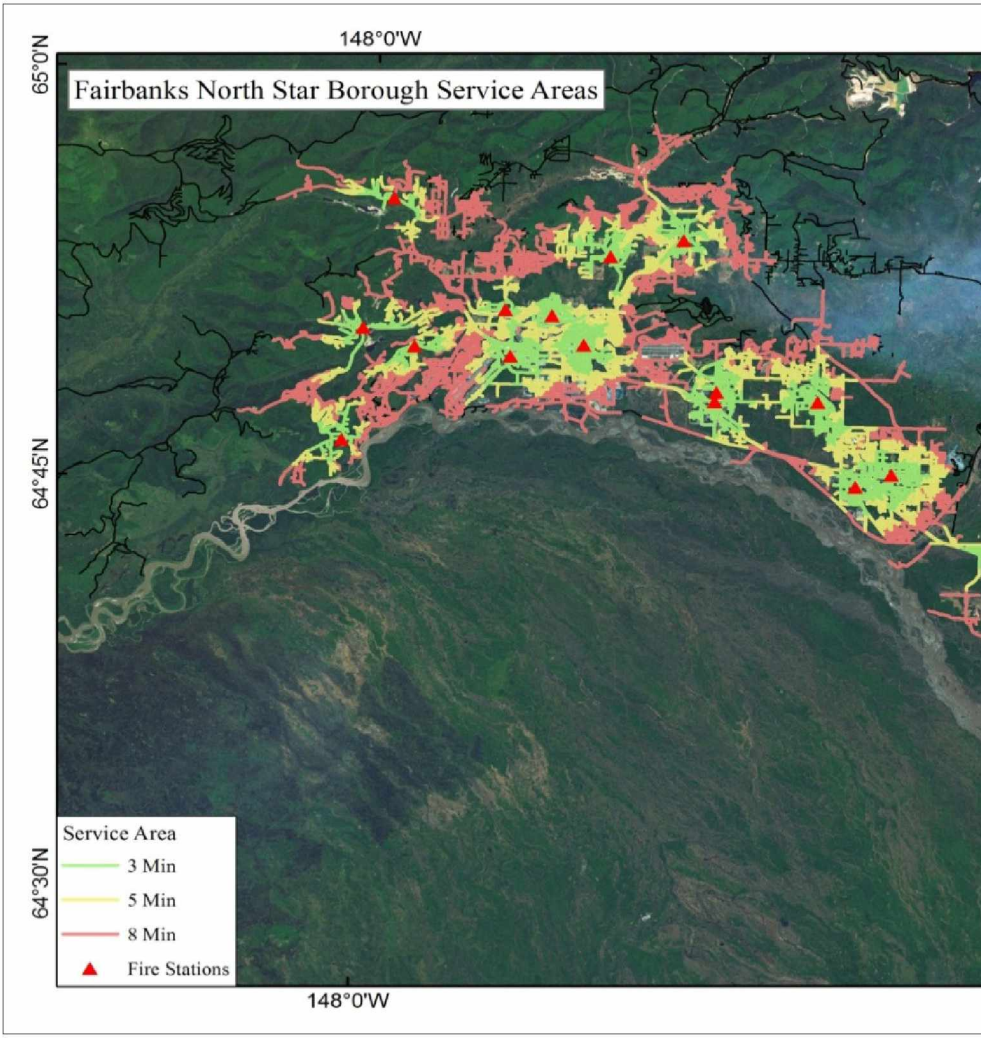
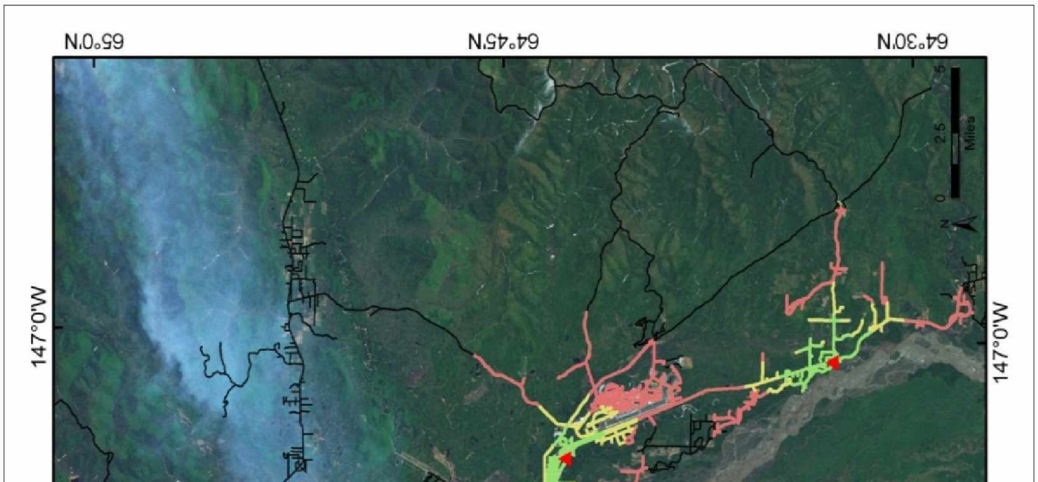


Figure A.1: Overall service area map for FNSB.


65°0'N
64°45'N
64°30'N
147°0'W
147°0'W
N
0
2.5
5
Miles

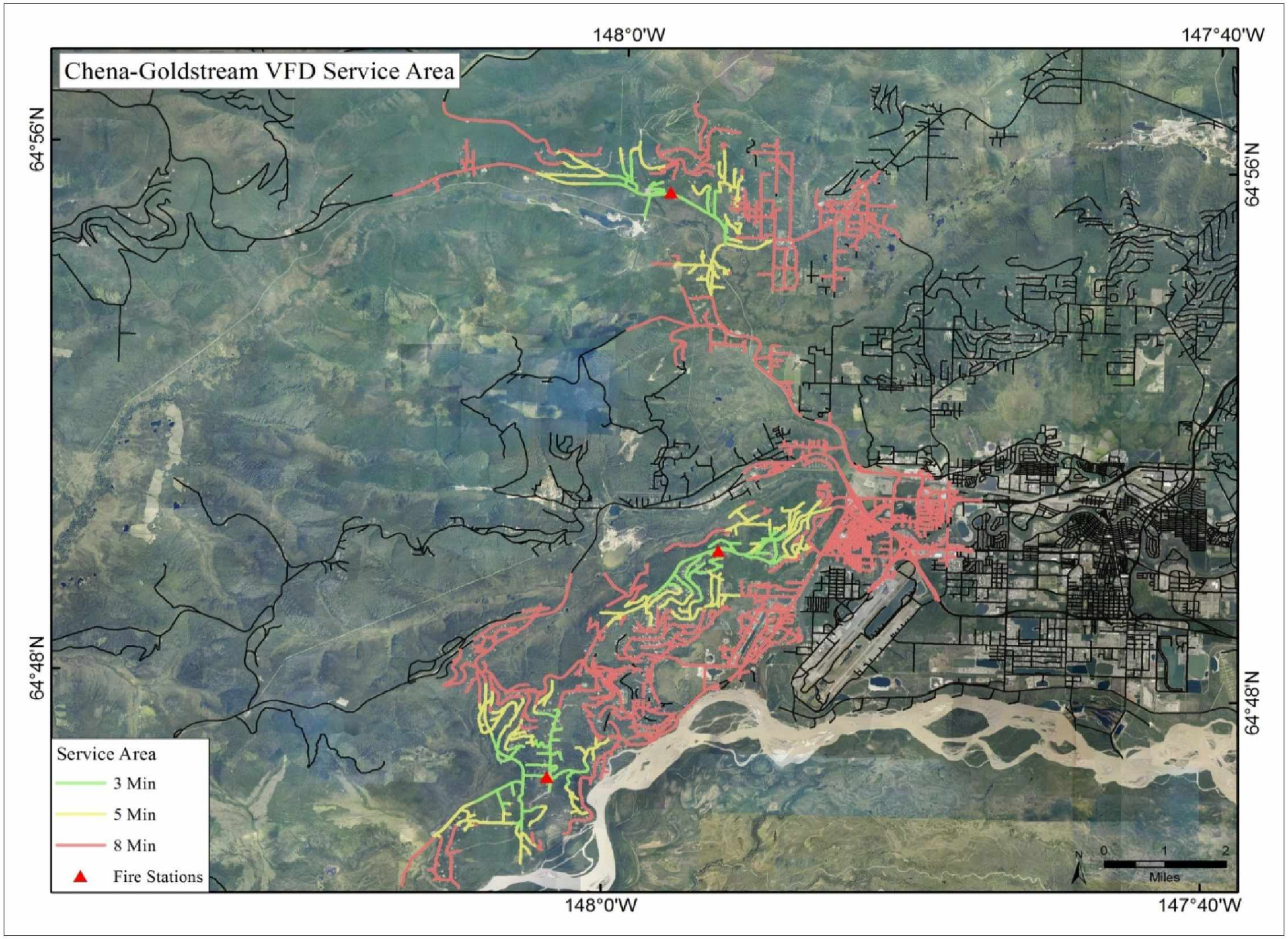


Figure A.2: Service area map for the Chena-Goldstream Volunteer Fire Department.

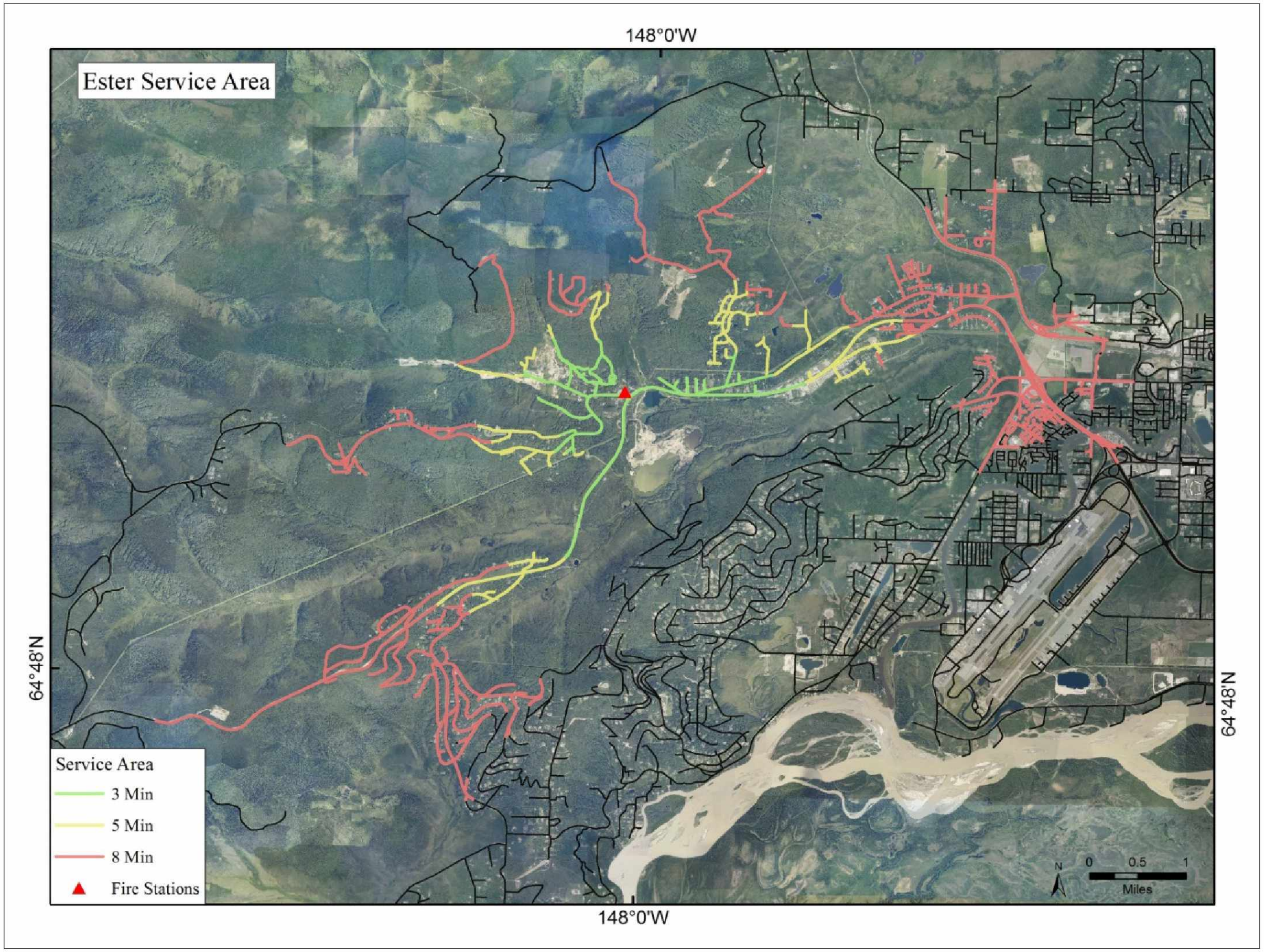


Figure A.3: Service area map for the Ester Fire Department.

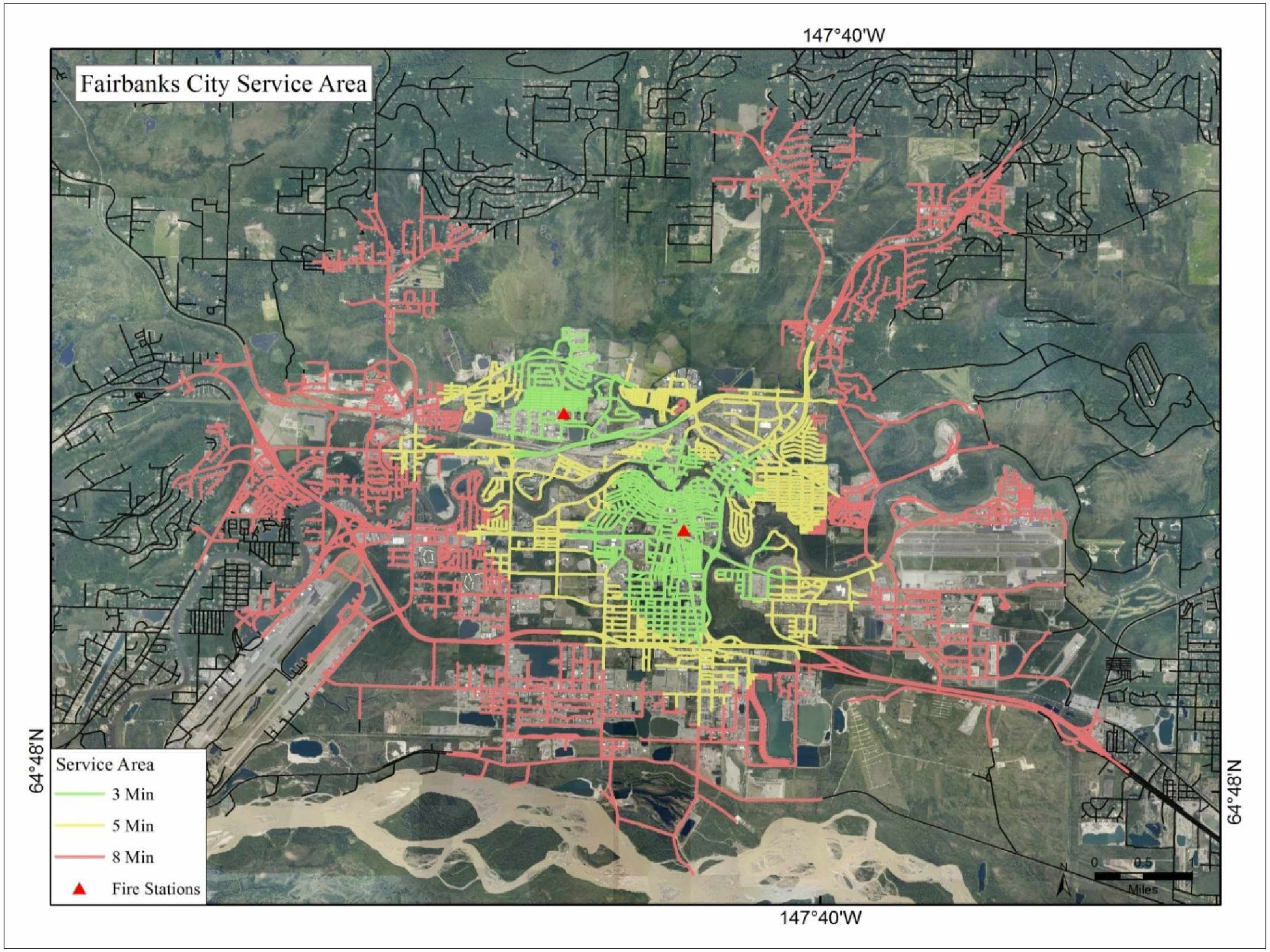


Figure A.4: Service area map for the Fairbanks City Fire Department.

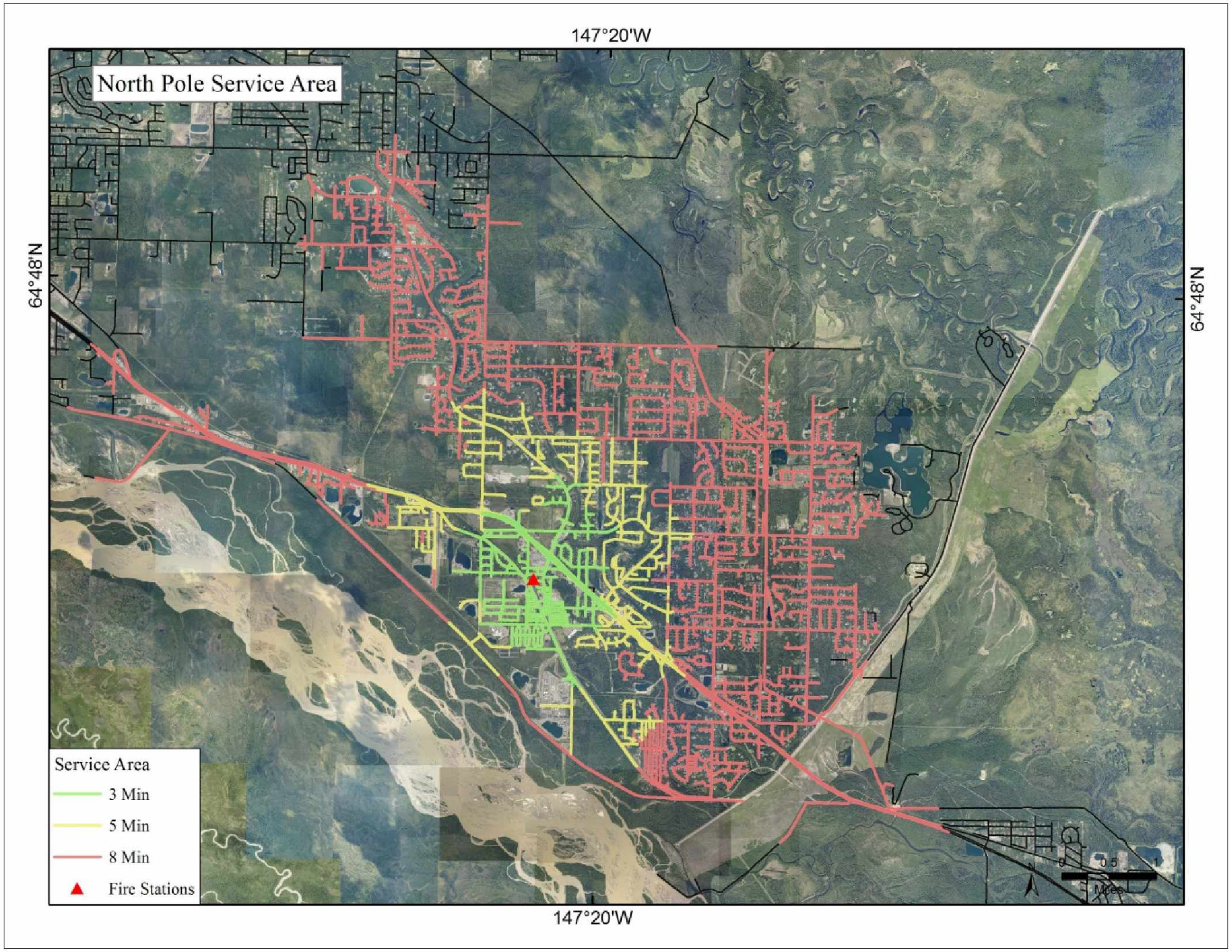


Figure A.5: Service area map for the North Pole Fire Department.

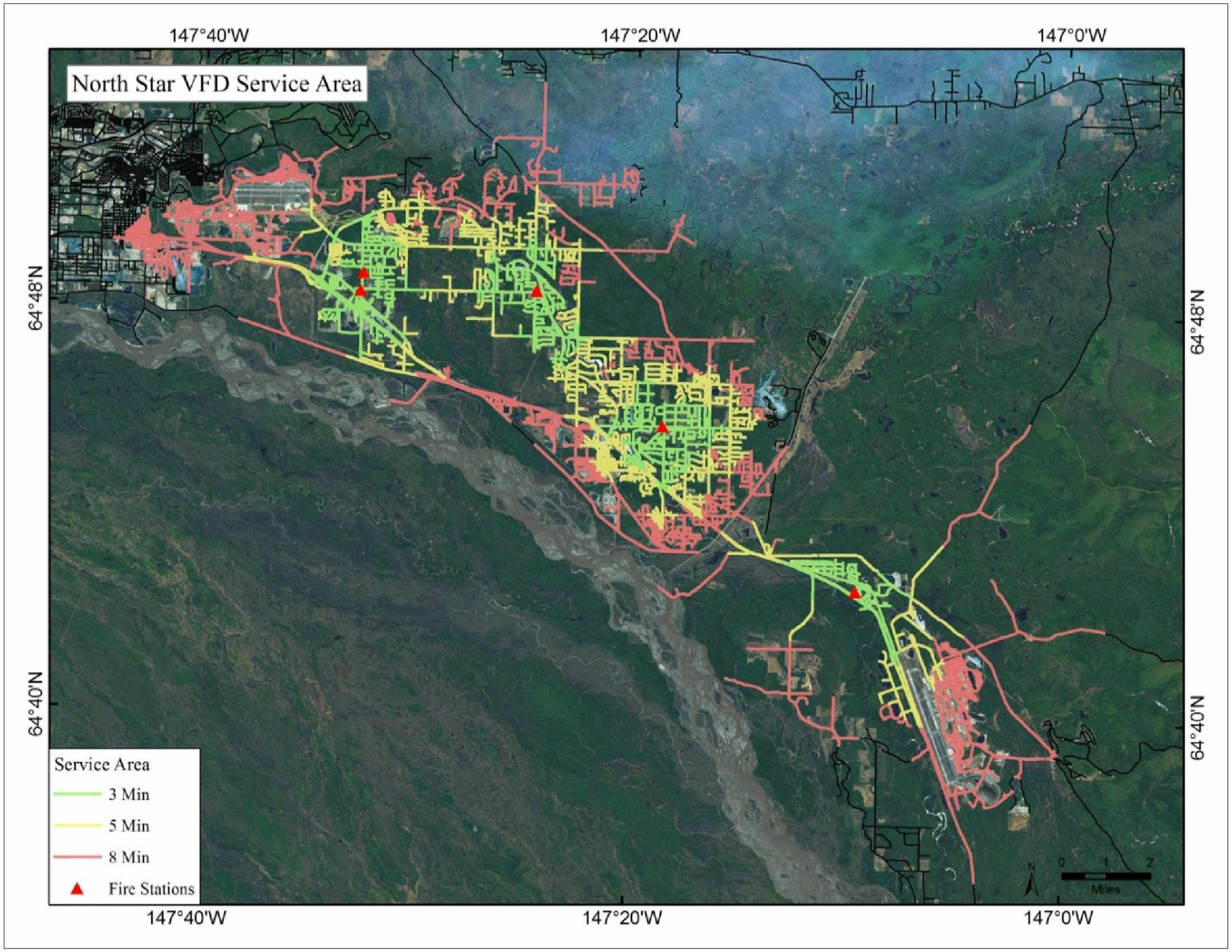


Figure A.6: Service area map for the North Star Volunteer Fire Department.

Figure A.7: Service area map for the Salcha Rescue Department.

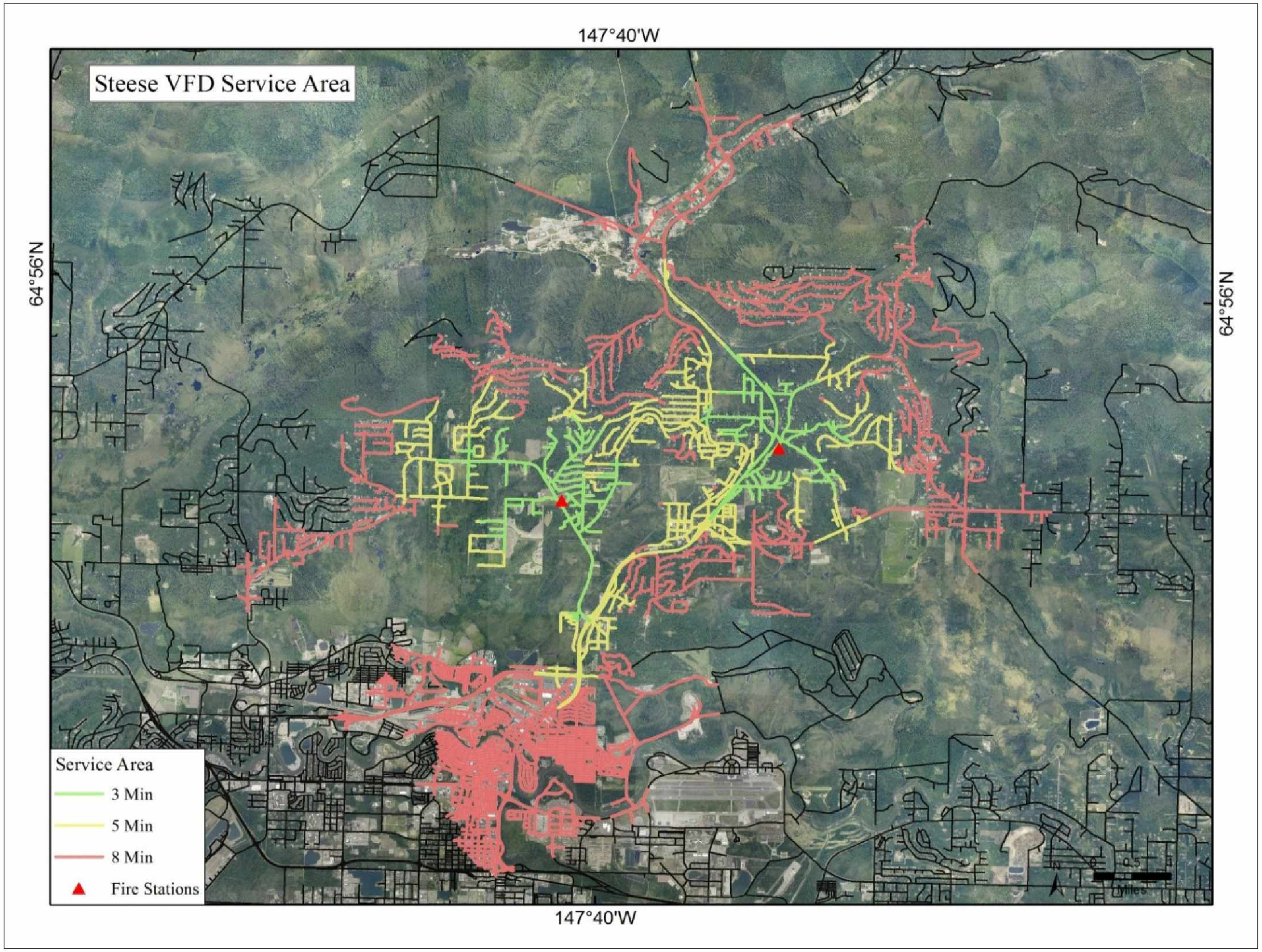


Figure A.8: Service area map for the Steese Volunteer Fire Department.

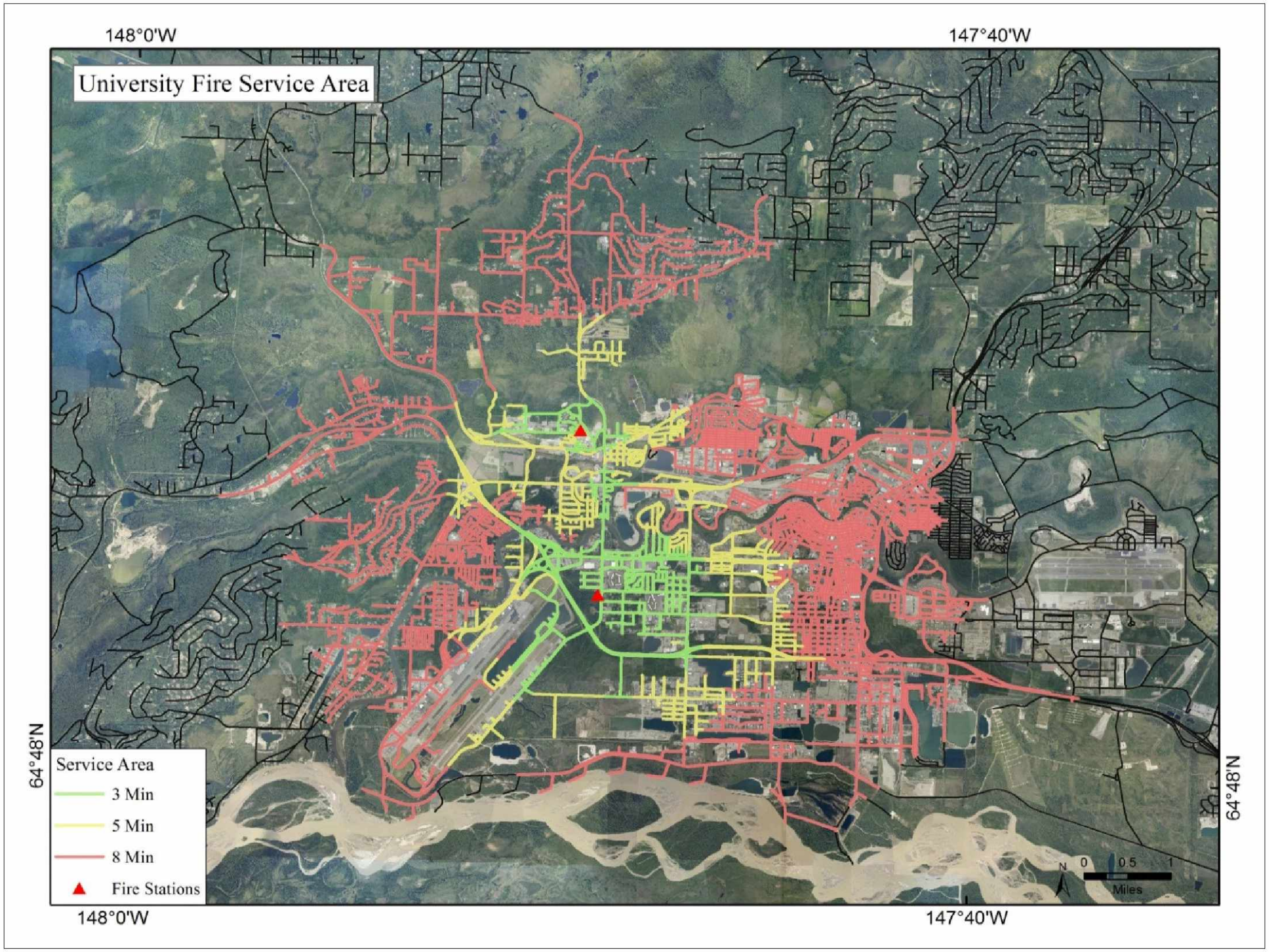


Figure A.9: Service area map for the University Fire Department.

Appendix B: Step-Wise Processes

B.1 Average People per House Calculations

The following is a step-by-step process followed to first merge the population spreadsheet with the census block shapefile and then calculate an average person per house figure.

1. The population spreadsheet was imported into ArcMap and saved as a .dbf table.
2. Each census block in the block shapefile has a unique identifier in a field called "GEOID10". "GEOID10" included the state code, county code, tract code, and the individual block number. For example a GEOID10 block code could look like: 020900019003036, which broke down into State code 02 (Alaska), county code 090 (FNSB), tract code 001900 and block number 3036. Table 3.1 is an example of the attribute table of the Block shapefile.
3. In the population table each block was spelled out and therefore did not have a unique number identifier that could be used to compare the population total to the actual block shape. Each row contained the tract number and block number listed in separate columns. Table 3.2 shows an example of the original census spreadsheet.
4. To convert the population table into a form that could be joined with the actual block shapefile a field was added to the population table called "GeoID".
5. The Field Calculator tool was used to calculate the "GeoID" value for each row using the following expression: "02090" + [CensusTract] + [Block]. This gave each row in the population table a corresponding ID to each block in the shapefile.
6. The Join Field tool was used join the population table with the Block shapefile. The Block shapefile was the Target with the join field set to "GEOID10"; and the population table was the Join with the join field set to

"GeoID". This join produced a block shapefile that had the population and housing totals for each block polygon in the Borough.

7. To derive the average population per house it was necessary to assign each point in the FNSB address shapefile to a census block. The Spatial Join tool was used to do this with the Target set to the FNSB Address shapefile and the Join was the census block shapefile. The Join Operation was 'One to One', the Match Option was 'Within', and 'Keep all Target Features' was checked. This produced a new point shapefile called "Address_Block_Join" that had all the address points assigned to their respective block.
8. The Frequency tool in the Analysis Toolbox was run on the resulting "Address_Block_Join" shapefile. The Frequency Field input was the 'GeoID' field. This produced a separate table, "addressFreq" that listed how many times each 'GeoID' code was listed. In other words, how many houses were in each block.
9. The Join Field tool was then used to join the frequency table back to the "Address_Block_Join". This produced a field in the block shapefile with total number of addresses per block.
10. A field called "AddressPop" was then added to the block shapefile. The Field Calculator tool was then used to calculate values of "AddressPop" by dividing the population field in the block shapefile with the "AddressFreq" field. Basically, it took the total population for each block and divided it by the total address count for each block giving an average population per house.
11. The result of these calculations was one polygon shapefile that had population totals for each block, address totals for each block, and average population per house for each block. Table 3.3 in the main thesis, shows an example of the final attribute table for this shapefile.

Appendix C: Evacuation Map Book

The color version of the evacuation map book is on the CD included in the pocket.